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# VENTILATION

## Of Central Station Buildings and Equipment

A Report of the Subcommittee on Ventilation of the Electrical Apparatus Committee, Technical National Section

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# VENTILATION

## Of Central Station Buildings and Equipment

*A Report of the Subcommittee on Ventilation of the Electrical Apparatus Committee, Technical National Section*

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# VENTILATION OF CENTRAL STATION BUILDINGS AND EQUIPMENT

*Ventilation and its concomitants have reached such an importance in the operation of central station buildings and equipment, including cable ducts, that for the reports of 1923 it was deemed advisable that there should be a simultaneous treatment of the subject by the Prime Movers and the Electric Apparatus subcommittees.*

*A great number of subjects for investigation was suggested. These, being of such an overlapping and varied nature, indicate that further segregation should be made for subsequent treatment; a large amount of the data presented deals with proposed activities or with installations now in the experimental stage.*

*Considerable data and discussion of a general nature dealing with the employment or conditioning of masses of air have been included for the sake of ready reference in connection with the presentation of present practice.*

## MOVEMENT OF AIR

The ventilation of electrical apparatus is to be distinguished from general ventilation which contemplates the removal of not only heated air but moisture and fume or dust laden air. In reality ventilation of electrical apparatus with but few exceptions is a cooling application and as such can be divided into two classes, direct and indirect.

In the former come such applications as the cooling of enclosed machines, such as generators, motors and transformers. The direct cooling is accomplished by forcing air through the machine so that by contact with the radiating walls of the machine heat is conducted to the air.

In the second class come such applications as cooling substations or rotary rooms. This is an application that is usually termed "ventilation." It is indirect cooling because the machine radiates its heat to the surrounding air and the surrounding air is removed and replaced by outside air.

Inasmuch as diffusion prevents the absolute removal of every cubic foot of air and its replacement by outside air, ventilation becomes a dilution process and because of this the results obtained will be dependent upon the degree of dilution. If the supply of air is unlimited, such as would be the case if the machine were out of doors and a breeze blowing across it, the temperature around the machine would be the temperature of the air, but as machines have to be housed in a building such an air supply is impractical and the temperature of the room can be expected to be something above the temperature of air supplied. This can be likened to an attempt to clarify muddy water by adding clean water to it. It takes a large volume of the clean water to clarify a small volume of muddy water.

In many respects, we are both fortunate and unfortunate in the medium of air for cooling and ventilating. We are fortunate in that the supply is unlimited and costs only for the handling; we can handle large volumes for a small expenditure of power; advantage can be taken of natural convection currents to secure the movement of considerable volumes of air. We are not so fortunate in its low specific heat which at constant pressure is usually given as 0.2375. This, coupled with the specific weight of 0.075 pounds at 65 deg. fahr. requires the use of a large volume of air to absorb a small quantity of heat. In fact $\frac{1}{0.2375 \times 0.075}$ or 56 cu. ft. heated through one degree fahr. are necessary to absorb one B.t.u. Air supports combustion which makes it undesirable from an electrical standpoint. Still air is an excellent non-conductor of heat, and to be effective for cooling the air must be kept in motion. Most unfortunate for its use with electrical apparatus is the solid matter that it carries in suspension. In spite of its many drawbacks there appears at present no simpler or more economical means of cooling much electrical apparatus than by the use of air.

Because it requires fifty-six cubic feet heated through one degree fahr. to absorb one B.t.u., the volume of air necessary to cool a large generator becomes enormous and may amount in thirty or forty minutes to a weight equal to that of the generator itself and more than the weight of steam supplied to the turbine to drive the generator. To move such a weight at velocities from 1000 feet per minute to more than a mile a minute requires the expenditure of considerable power. Consequently, some knowledge of air flow should be valuable to the designer and operator of air cooled electrical apparatus.

The flow of air is in accordance with the fundamental law of falling bodies; $v = \sqrt{2gh}$. As this velocity is in feet per second, and the head in feet of the medium flowing, it is necessary to change this into a form that will give the relation in feet per minute and the head in inches of water the usual basis of considering air flow.

Let k equal density of water = 62.4 lb. per cu. ft. at 70 deg. fahr.

Let d equal density of air flowing.

Let $h_v$ equal velocity head measured in inches of water. This head is equal to total or impact head minus static or compression head.

Then $12\,dh = h_v\,k$ or $h = \frac{h_v k}{12\,d} = \frac{v^2}{2g}$ or $h_v = \frac{12d\,v^2}{2\,gk}$ or $v = \sqrt{\frac{2\,gh_v k}{12_v}}$

or $v = 18.27\sqrt{\frac{h^v}{d}}$. At 65 deg. and standard conditions of barometer, d equal 0.075. Then $v = 66.75\sqrt{h}$. This gives us v in feet per second, so, to get the velocity in feet per minute we have $v = 60 \times 66.75\sqrt{h}$ or $4005\sqrt{h}$. This is usually used as $4000\sqrt{h}$ which means that a velocity of 4000 feet per minute will put up one inch water pressure.

One inch of water pressure equals 5.2 pounds per sq. ft. As most fans are designed for working against pressures ranging from ¼ in. to 5 in. water pressure it is evident that they are to be termed very low pressure machines.

The horse-power to move air is the weight times the velocity divided by thirty-three thousand. If the pressure is in inches of water 5.2h equals the pressure per sq. ft. and the volume equals the velocity in ft. per minute times the area of the pipe in sq. ft. Then $\text{H.P.} = \dfrac{\text{Vol. (cu. ft. per min.)} \times 5.2h \text{ (Pres. in in. water)}}{33{,}000}$. H.P. = 0.0001575 volume times pressure. For one inch of water (the total pressure or impact) this equals 0.15 horsepower per 1000 cu. ft. This power is air horse-power and for average practice a fan efficiency of 50 per cent may be considered a good average. The brake horse-power is equal to approximately .3. It is evident then that a generator requiring 50,000 cu. ft. per minute which may be under a total pressure of seven inches of water requires the considerable expenditure of 105 H.P.

The velocity at which air moves is a measure of the power required, for the velocity can only be secured through the conversion from a pressure necessary to produce that velocity. Consequently, if there is a restricted area in a duct system, the power required to put the air through the restricted opening may exceed that to overcome the friction effect of the rest of the duct system.

Most tables on the friction of air are based on Weisbach's experiments and the formula $P = f\dfrac{L}{d}\dfrac{v}{2g}$ where "P" is the pressure loss in pounds per square inch, where "f" is the coefficient of friction, "L" the length of the pipe in feet, "d" the diameter in inches and "v" the velocity in feet per second.

Converting this into the loss in pressure per sq. in. in ounces, the formula becomes $p = \dfrac{Lv^2}{25000d}$. From this fundamental formula many tables and charts have been devised for the friction in 100 feet of pipe from round to rectangular. In this formula the expression $\dfrac{L}{25000d}$ is on the basis of "L" in feet and "d" in inches. It is customary to consider friction loss in terms of velocity pressure, and the length in terms, of diameter; consequently, if we put the "d" in the expression in terms of feet "D," $\dfrac{d}{12} = D$ or $d = 12D$. Putting this in the equation, $p = \dfrac{Lv^2}{25000d}$ we get $p = \dfrac{Lv^2}{25000 \times 12D}$ or $L = \dfrac{25000p \times 12D}{v^2}$ or $L = \dfrac{12 \times 25000pD}{v^2}$.

From the foregoing we had $v = 66.75\sqrt{h}$ where "h" is in inches and to put this in ounces we have $p = \dfrac{h}{1.73}$ for one oz. = 1.73 inches. Therefore, $h = 1.73p$ or $v = 66.75\sqrt{1.73p}$ or $v = 87.70\sqrt{p}$. Hence squaring "v" and substituting in the equation $L = \dfrac{12 \times 25000pD}{v^2}$ we get $L = \dfrac{12 \times 25000pD}{(87.70)^2p}$. Therefore, when the length is such that the friction pressure equals the velocity pressure we can cancel "p" and we get $L = \dfrac{12 \times 25000D}{(87.70)^2} = \dfrac{300000D}{7700}$ or $L = 39D$ which means that in a length of pipe equal to 39 diameters of the pipe the pressure loss due to friction will be equal to the velocity pressure. In practice it is usual to consider this as 40 diameters instead of 39.

There are some investigators who consider Weisbach's coefficient too high. However, it is a safe figure to use because the average piping system will not be as carefully made as would be a test pipe for laboratory purposes. Hence the formula using Weisbach's coefficient gives us a factor of safety for the inequalities of average workmanship.

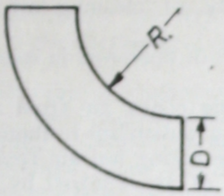
In many generating and substations air ducts are constructed of concrete. Attention should be called to the porosity of average concrete. When such construction is used for air ducts in which pressures of several inches of water will be maintained the interior should be coated with neat cement and painted with a good oil paint. The average friction loss in concrete is figured at a pressure equal to the velocity pressure in 20 diam. for smooth concrete, and as low as 15 diam. for rough concrete. These are figures used by the B. F. Sturtevant Company.

For the loss in duct constructed of brick there has been deduced from Babcock & Wilcox data on chimneys that the friction loss in pressure is equal to the velocity pressure in a length equal to 13 to 15 diameters.

In as much as most air handling systems are working at low pressures, care must be taken to permit an easy flow. In the case of steam moving at several thousand feet per minute and at pressures of 200 pounds and more per square inch the loss due to a sharp right angle elbow is not of much consequence as it is a very small percentage of the total pressure in a pipe system; however, the loss due to a short right angle elbow is equal to the velocity pressure and that may be from 10 to 25 per cent of the total pressure of an air duct system. The

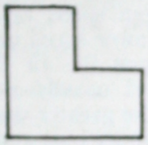
## TABLE I

90° Elbow



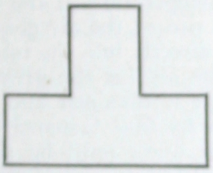
| Ratio $\frac{R}{D}$ | Pressure Loss | Additional Length Pipe |
|---|---|---|
| 2.0 | .125 V P | 5 D (in feet) |
| 1.5 | .15 V P | 6 |
| 1.25 | .225 V P | 9 |
| 1.0 | .25 V P | 10 |
| .75 | .40 V P | 16 |
| .50 | .75 V P | 30 |

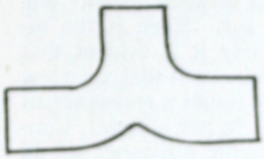
90° Angle



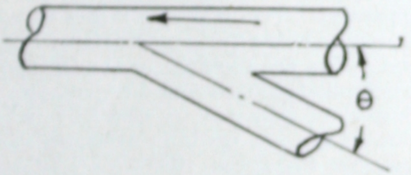
Pressure loss = 1 V P
=40 D

Square Turn
Pressure loss
= 1 V P
= 40 D



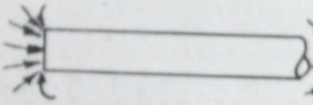


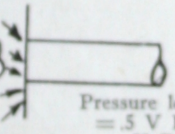
Square Turn
With Rounded Corners
Pressure loss
= .15 V P
= 6 D



| Angle θ | Pressure loss |
|---|---|
| 90 | 1 V P — 40 D |
| 60 | .44 V P — 17.5 D |
| 45 | 0.22 V P — 8.8 D |
| 30 | 0.17 V P — 6.8 D |
| 15 | 0.09 V P — 3.9 D |

Entry head loss in plain pipe
Entry head loss in plain pipe with plate

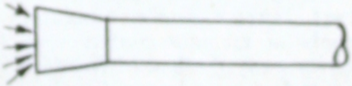




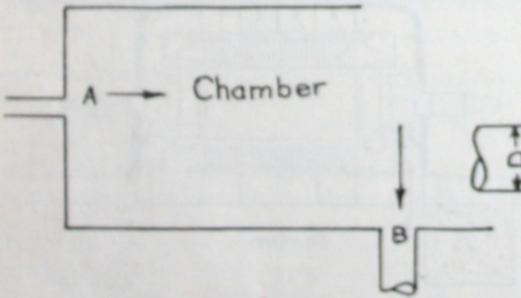
Pressure loss
= .5 V P
= 20 D

Pressure loss = 1 V P
= 40 D

Entry head loss conical intake

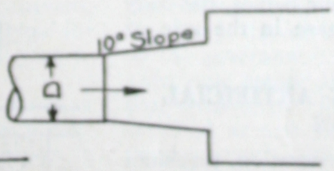


Pressure loss = 0.25 V P
= 10 D

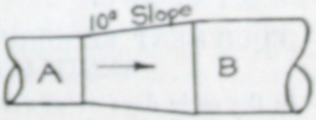


Pressure loss at A
= 1 V P = 40 D

Pressure loss at B
= .50 V P
= 20 D



Pressure loss
= .50 V P
= 20 D



Where area B = 2 times area A
Pressure loss
= 0.225 V P
= 9 D

loss due to various restrictions is given in Table I. These are in terms of velocity pressure and of the friction in straight pipe in terms of diameters.

The loss through air washers is usually ¼ in. at 500 ft. per minute velocity. This is the velocity through the gross area. For other velocities the loss is proportional to the square of the velocity.

Cotton cloth, when used as an air cleaning or filtering device, should be impregnated to be noninflammable. The loss is some function of the velocity. If the interstices are considered an orifice the loss will vary as the square of the velocity.

A. E. Stacey (May, 1921—*Journal A. S. H. & V. E.*) found that the resistance through canton flannel was directly as the velocity up to fifty feet per minute. As such velocities are believed to be below the critical velocity and smooth flow without eddies resulted the relationship between velocity and resistance may be accounted for. Even if the resistance did vary as the velocity it is evident that the area of cloth filters should be such that very low velocities will result, as Stacey found a resistance of 0.13 in. water gauge loss at 50 ft. per minute. Consequently, at 1000 feet velocity the resistance would be at least 2.60 in.

Stacey further showed that silk clogged with carbon particles had a resistance seven times that of the same piece of silk clean. With a fabric such as canton flannel the resistance does not increase so materially with an accumulation of dirt. Cheese cloth is commonly used for filters but is not so desirable as flannel, because of the lack of nap, and while it may offer a slightly lower resistance to the flow of air, its filtering property is less than flannel and its resistance materially increases with an accumulation of dust.

Air movement is necessary to produce ventilation. Such air movement is beneficial to both operators and machines. In the case of operators it brings a fresh supply of air into contact with the body. This air carries away the heated envelope surrounding the body and of most importance it carries away the moisture that is being continuously brought to the skin.

It is through evaporation that a large measure of the heat balance of our bodies is maintained. Naturally if we restrict this cooling effect which comes from evaporation and allow an envelope of highly saturated air to enclose our bodies, the body temperature rises with an increase in the rate of pulse and discomfort.

## EQUIPMENT REQUIRING ARTIFICIAL VENTILATION

In the early days of power generation, machines were of small size, slow speed, and were isolated. The growth of the power load, coupled with the increase in the size and rotative speed of machinery, have made it necessary to enclose the larger high-speed apparatus. This was occasioned by the following conditions:

(1) Windage noise of high speed machinery.

(2) Need of pressure chambers in long core machines to force air through to center of core.

(3) Necessity of cleaning air going to large machines.

(4) Comfort of operators in stations of restricted space.

(5) Obtaining cooler air from outside.

(6) Avoiding possibility in motor generator sets of one machine taking hot air from the other.

The amount of air required by a large machine varies from 75 to 100 cubic feet per minute per kilowatt loss; the lower range being used for large high speed turbines, while the upper range is for slower speed units. The amount of air is dependent upon the air temperature rise through a machine and usually varies between 18 deg. and 24 deg. The greater the amount of air circulated, the lower the air rise, and the lower the hot spot temperature. The hot spot temperature is the machine rise above the temperature of the leaving air, so the temperature rise of the air going through the machine enters directly into the total temperature.

The air for the great majority of enclosed machines is obtained and propelled through the machine by fans fastened to the rotor. The inlet and outlet ducts must be short, having few bends, of liberal radius, and of ample cross sectional area.

The pressure drop varies in different classes of apparatus. Ten to twelve inches of water pressure is required in a turbo-generator while only one to two inches are required in synchronous converters, synchronous motors and d.c. generators. For other classes of apparatus, especially where external blowers are not used, air velocities should be kept low, not to exceed 1000 feet. In self-ventilated, enclosed machines, the velocity of air in the air ducts ranges between 1000 and 1500 feet per minute. For force-ventilated machines, with separate blowers, the air velocity in the ducts may be increased to between 2000 and 3000 feet per minute.

### A. C. Turbo-Generators

Figure 1 shows a standard method of enclosing a turbo-generator. A double end bell, at each end, is bolted to the frame. The cooling air enters the outer end bell at the bottom and flows through the inner end bell around the shaft to the fan blades. The space between the inner end bell and the core is a pressure chamber which forces the air through the various ventilating paths in the machine. The

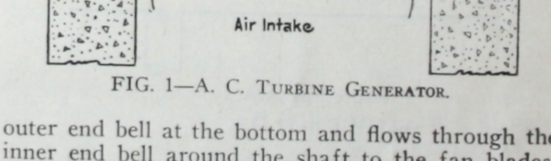


FIG. 1—A. C. Turbine Generator.

air outlet can be through the top into the room, through the top to the outside by a duct, or through the bottom.

Up to date, the type of enclosing bell shown in Fig. 1, seems to have been satisfactory from the standpoint of noise. Power houses are usually located at a distance from residential districts, therefore the roaring noise becomes much reduced and muffled by the time it is carried to the outside air. The noise is not sufficiently muffled so that the power house is quiet, but the noise is of low pitch and not seriously objectionable to operators.

### Vertical Water Wheel Generators

On large vertical water wheel generators and especially where there are several in the same station, it is often desirable to discharge the hot air to, and draw the cooling air from, the outside of the building. This condition is especially desirable in summer to avoid excessive temperature in the generator room. In winter time provision is usually made for discharging a portion of the hot air into the generator room for heating purposes.

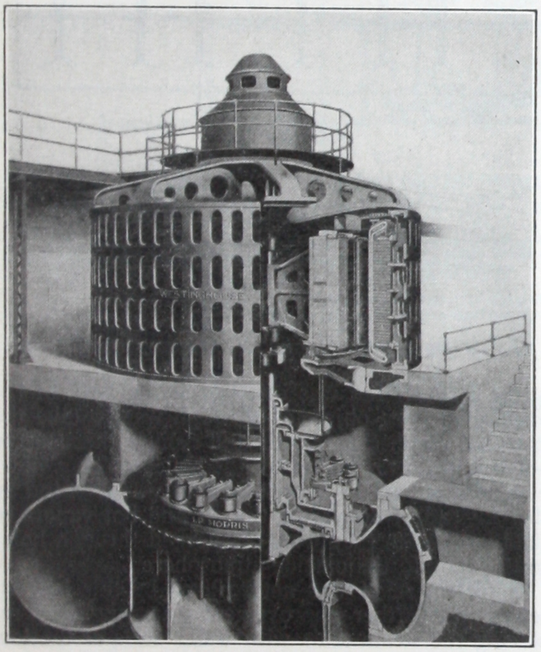


FIG. 2—VERTICAL WATER WHEEL GENERATOR.

On the lower speed vertical units which have an open spider construction, the above condition is easy to overcome. The cooling air is usually drawn in from the pit below the generator (Fig. 2). The pressure created by the poles and blowers is such as to draw air in from both sides of the machine and force it into the air gap and between poles and out through the vent ducts in the core, the cooling air for the top of the machine being drawn up through the spider around the shaft. The upper part of the machine above the blowers and winding is closed to prevent air being drawn in at the top from the generator room. For discharging the hot air to the outside of the building, it is the usual practice to furnish a special cast frame, or a special sheet steel housing around the conventional open type cast iron frame, with provision for connection to discharge ducts to the outside of the building.

On large high speed vertical units where the high stresses make it necessary to use a solid rotor construction, such as rolled steel plates, and where the core is too wide to depend on drawing the air from the bottom of the machine, a different and more complicated construction is necessary.

A 28,000 kv-a., 11,000 volt, 3 phase, 50/60 cycle, 428/514 r.p.m. vertical water wheel type generator being built by the Westinghouse Electric & Manufacturing Company for the Southern California Edison Company, is a machine of this type, and a brief description of the ventilation of the machine with special provision for getting the air to the top of the machine follows:

Figure 3 shows a cross-section of the machine. The fans "F" are of the inclined shrouded type, efficiently designed and of such proportion as to give a pressure corresponding to ¾ in. of water, in addition to that required to force the air through the generator, to take care of the pressure drop in the cooling air through humidifiers. As shown in the figure, the air is drawn in from the bottom part of the generator. The machine has a conventional open type frame and a double sheet steel housing built around it. The upper part of the housing is attached to and has the same slope as the upper bracket arms. Although the individual chambers of the air housing are eccentric with respect to the generator, the outer contour is circular (except where the discharge duct is attached at "D") and concentric with the generator. The ducts for the cooling air open into the pit below the generator and into the chamber "A." The air for the bottom half of the unit is drawn directly from the pit. The air for the upper half of the generator is drawn up through the chamber "A" and discharged into the opening or chamber between bracket arms.

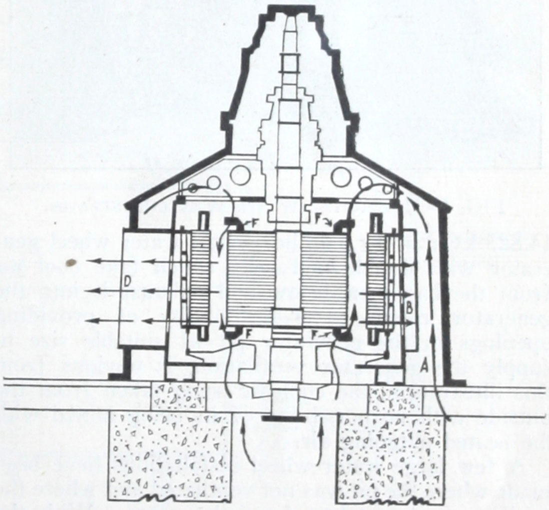


FIG. 3—VERTICAL WATER WHEEL GENERATOR.

Holes are provided in the webs of the bracket arms through which any unequal discharge of air into the chambers between bracket arms can be equalized. The air goes directly into the upper part of the machine from this chamber and is drawn into the machine from the top and bottom, thence forced through the vent ducts in the core and out the holes in the frame to the discharge chamber "B" and finally from the discharge D to the outside of the building. The general circulation of air is indicated by arrows.

### Horizontal Water Wheel Generators

The large horizontal generators are enclosed in the same manner as turbo-generators, and for essentially the same reasons. Fig. 4 illustrates a 14,825 kv.a. 450 r.p.m. horizontal water wheel generator with double end bells which take cool air from the basement below and exhaust it into the generator room. The desirability of providing openings in the generator pit of suitable size to supply the generator ventilation, is obvious from this illustration, the cool air being taken from the outside with no possibility of its being mixed with the heated outgoing air.

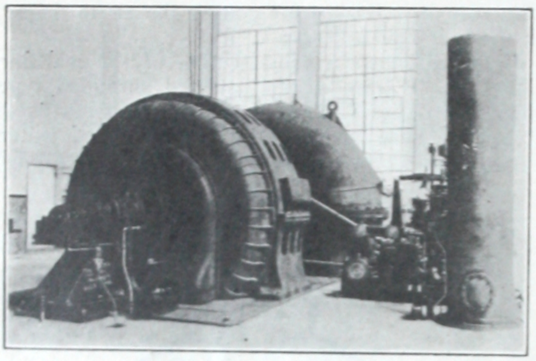


FIG. 4—Horizontal Water Wheel Generator.

A few large water wheel installations have been made where the pit was not ventilated and where the cooling air was taken from the room. With the relatively large volume of cooling air required, compared to the size of the room, the room air was hotter than the outside air and the generator unnecessarily penalized.

### Specific Cases

The ventilating system at the Connors Creek plant has undergone many changes since it was originally installed. To eliminate excessive dirt in the generators, an air washing system was installed, the idea being to take a sufficient quantity of air through the washer, blow this air directly into the head house and let the generators take their required quantity of air directly from the head house and discharge it at the pipe gallery level under the boiler room floor. From this point the blowers pick up the warm air, put it through the furnace grates and thence up the stacks. The first change made was to install a set of louvers in an attempt to govern the amount of air entering the intake. Following this, an opening in the intake was made connecting the head house and condenser rooms. This opening had louvers installed in it which provided a still finer adjustment of the air going to the generator and at the same time allowing the possibility of re-circulating some of the air from the turbine room.

Some time later, due to leakage of steam seals on two turbines, condensation on the sky lights of the turbine room became excessive.

To eliminate this trouble, canvas enclosures were temporarily built over and above these machines and a Venturi fan was installed at the peak of the enclosure. The object of this fan was to take the escaping steam and hot air and deliver them to the boiler room near the tops of the boilers. This, however, did not prove successful and was changed so that instead of delivering the air and hot vapors to the boiler room they were discharged through holes in the roof to the outside atmosphere.

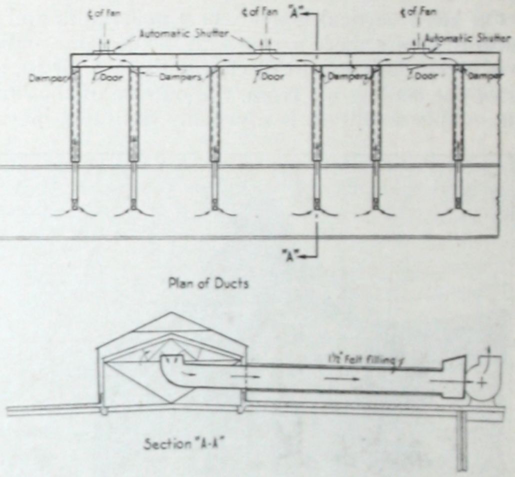


FIG. 5—Double Sky Light at Connors Creek Plant.

Sufficient relief was not realized by this last attempt and further improvement was sought by replacing the steam seals with water seals at the low pressure end. While conditions were somewhat improved by this reduction of escaping steam, they were not entirely satisfactory.

The latest attempt at improvement, as shown in Fig. 5, has been to put an additional sky light over the present one above the turbine room, the idea being to keep the inner sky light at a sufficiently high temperature so that condensation will be impossible. Ten intake pipes are brought through one side of the sky light to a common duct outside located on the turbine room roof. Each pair of these ten ducts is connected to a fan which discharges into the open.

From the experiences at the Connors Creek plant, there has been installed in the Marysville plant which has just been put in operation a system of ventilation, as shown in Fig. 6. This is designed to: first, cool the generator with washed air; second, collect and remove water vapor escaping

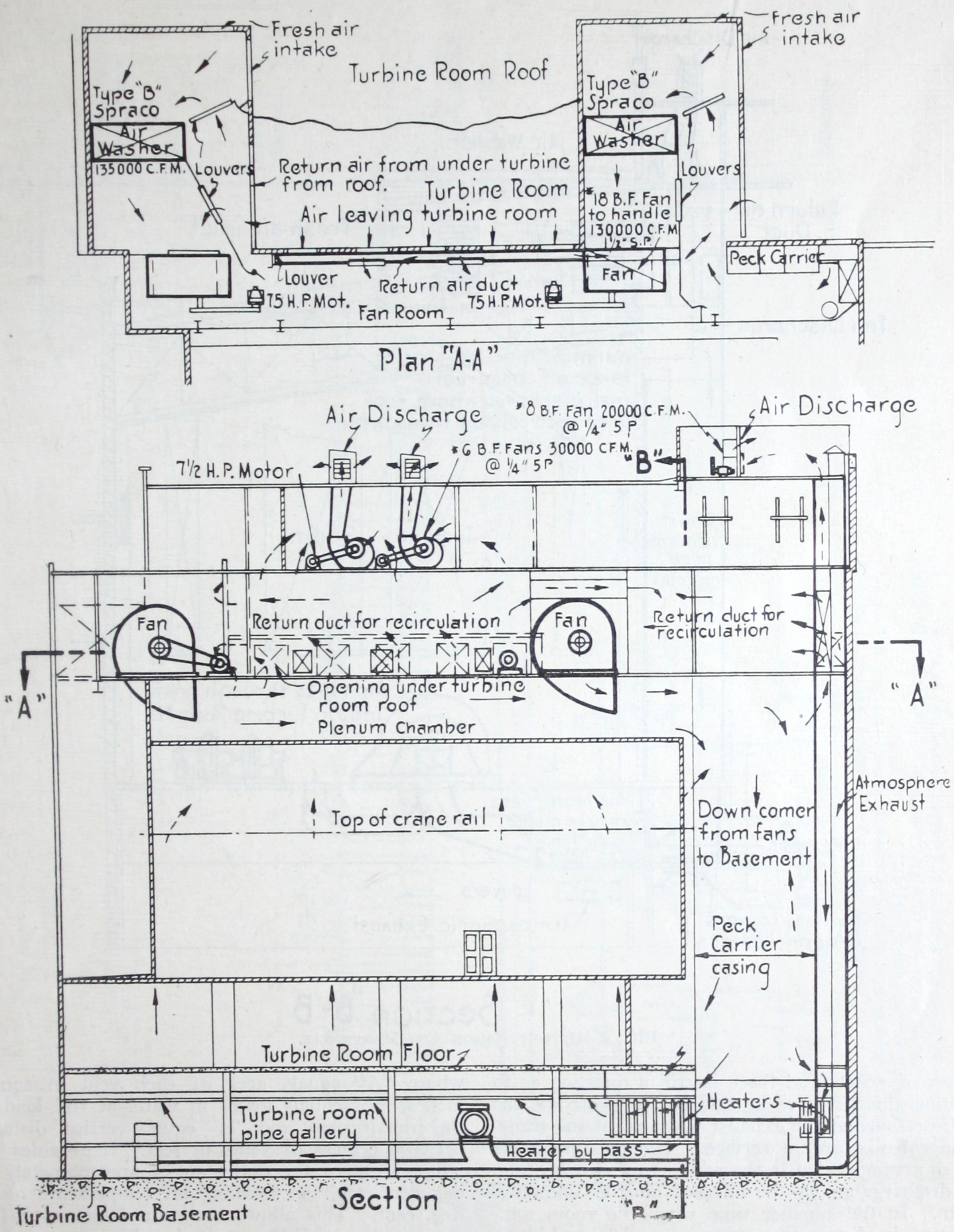


FIG. 6—Detroit Edison Co., Marysville.

from the turbine; third, prevent condensation on turbine room ceiling; and fourth, heat the turbine and condenser rooms in winter and cool with washed air in the summer.

**Transformers**

One of the latest schemes of air blast transformer ventilation which is to be used in the Elizabeth Street Substation of the United Electric Light & Power Company (Fig. 8) includes exhaust ducts arranged to take air directly from the outlet of the transformers and carry it to the exhaust outlets at the roof which not only provide lower room temperatures, but is also of some relief to the operator. In this particular case it was necessary to provide blowers having an operating air pressure of five

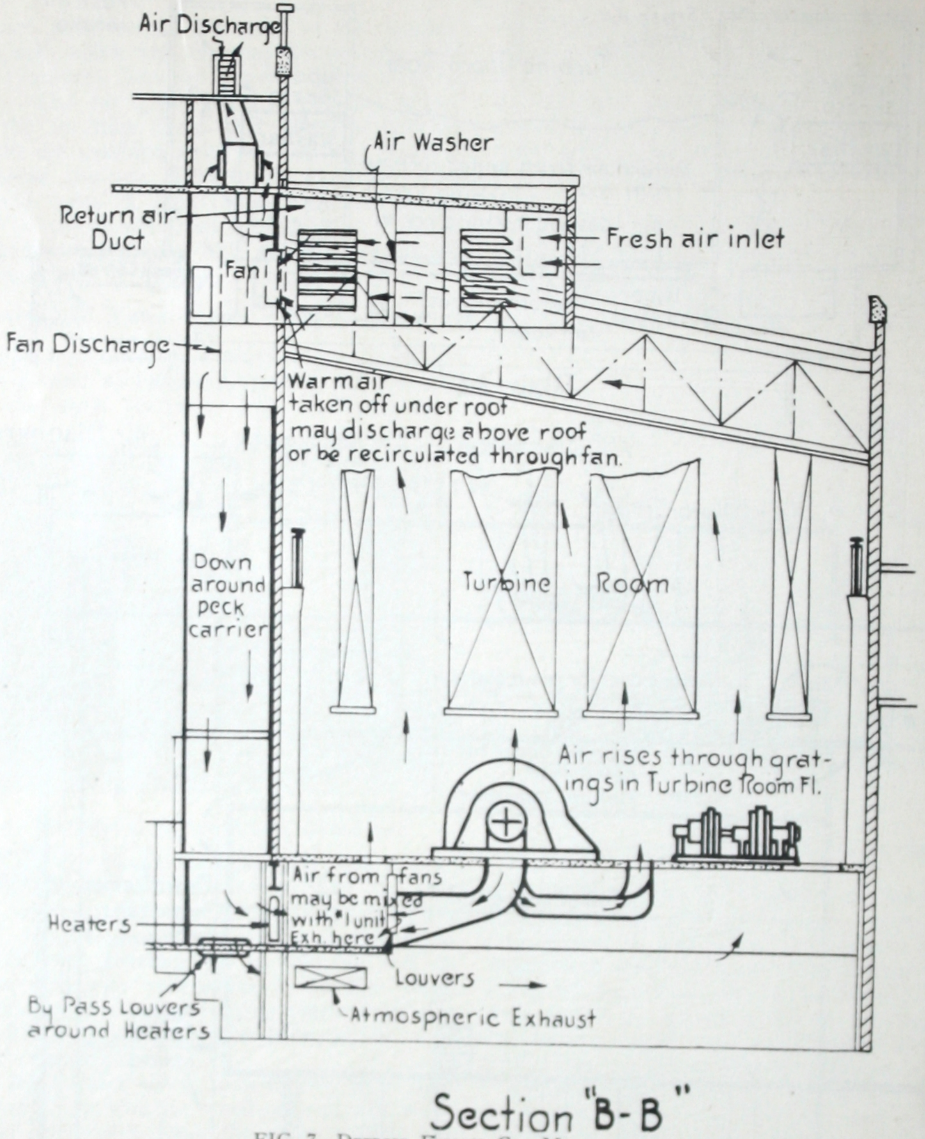

Air Discharge
Air Washer
Return air Duct
Fan
Fresh air inlet
Fan Discharge
Warm air taken off under roof may discharge above roof or be recirculated through fan.
Down around peck carrier
Turbine Room
Air rises through gratings in Turbine Room Fl.
Air from fans may be mixed with "I unit Exh. here
Heaters
Louvers
By Pass Louvers around Heaters
Atmospheric Exhaust
Section "B-B"

FIG. 7—DETROIT EDISON CO., MARYSVILLE.

inches of water, and there is still a question as to whether this pressure is sufficient to overcome the back pressure at the exhaust when all of the transformer banks are in service. The exhaust ducts are so arranged that in the winter time, for heating, the discharge air can be released into the operating room. In the summer time when the room temperature is of necessity very warm, additional blowers to ventilate the station itself are proposed, in which function they will also take care of the radiation from the outside surface of the transformers. In this station where the transformers were installed in vaults, the following formula for vents was worked out theoretically and then checked up by test:

$$A = \frac{P}{2.18} \sqrt{H}$$

where "A" equals area of each vent in square inches, "P" equals losses in watts at full load of the transformers and "H" equals vertical distance between centers of vents in feet. It provides for temperature of the outlet air of approximately 40 deg cent. with an intaking air temperature of 25 deg. cent. This allows a certain factor of safety to meet the A.I.E.E. standard ambient temperature of 40 deg. cent. Furthermore, no allowance is made for radiation from the walls of the vault, which fact provides an additional factor of safety.

Instances are cited by the Rochester Gas & Electric Corporation where oil insulated self-cooled transformers showing excessively high temperatures have been materially relieved by the installation of large windows in the building walls. In these cases, where the insurance companies have requested indi-

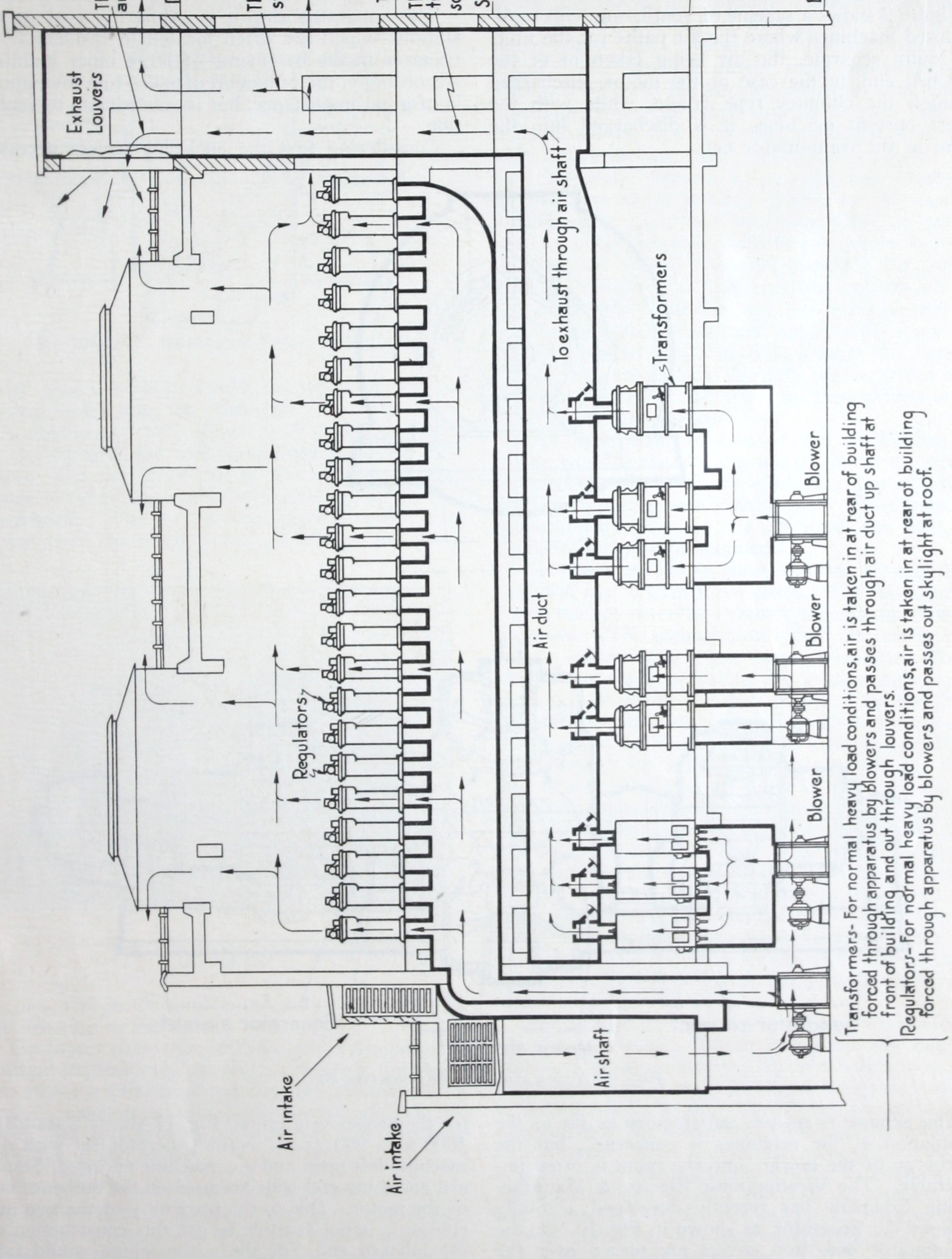

This air in separate air shaft
Roof
This air in main stair well
Third Floor
This air from transformer in separate air shaft
Second Floor
First Floor
Basement
Exhaust Louvers
To exhaust through air shaft
Transformers
Blower
Blower
Blower
Air duct
Regulators
Air shaft
Air intake
Air intake
Transformers- For normal heavy load conditions, air is taken in at rear of building forced through apparatus by blowers and passes through air duct up shaft at front of building and out through louvers.
Regulators- For normal heavy load conditions, air is taken in at rear of building forced through apparatus by blowers and passes out skylight at roof.

FIG. 8—UNITED E. L. & P. CO., ELIZABETH ST., SUBSTATION.

vidual fireproof compartments which would require artificial ventilation, objections have been satisfied by properly protecting the exposed surfaces with non-combustible material.

### Motor Generator Sets

Figure 9 shows a scheme of ventilation with semi-enclosed machines where the air paths for the units are quite separate, the air being taken in at the end bell and, in the case of the motor, discharged through the chimney type frame, while with the direct current machines it is discharged into the room at the commutator end.

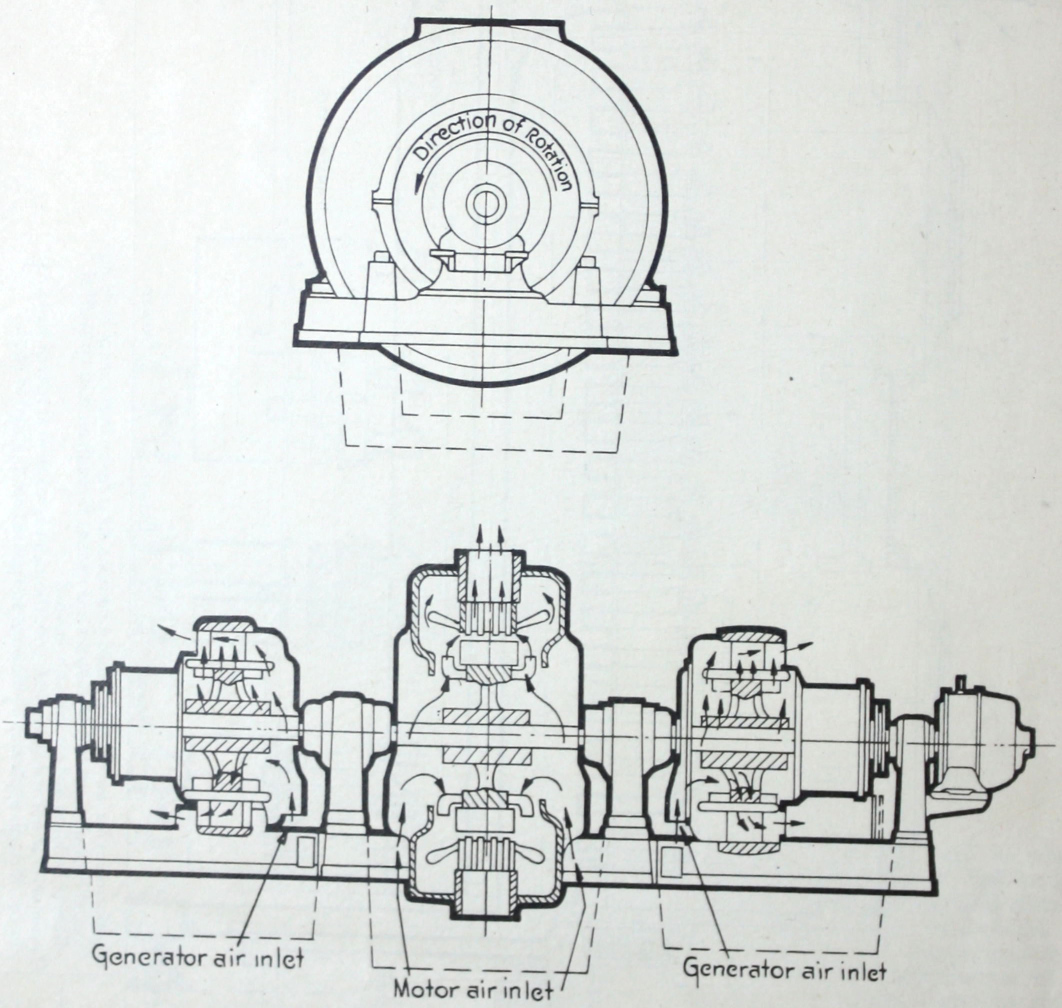


FIG. 9—AUTOMATIC MOTOR-GENERATOR SET.

This scheme is entirely satisfactory as far as the ventilation of the machines is concerned, but the discharge of the hot air into the room is often undesirable. The Westinghouse Electric & Manufacturing Company has recently developed a totally enclosed d.c. generator, as shown in Fig. 10. On the commutator end, iron covers are placed over the commutator with twelve glass windows around the circumference so that the commutator can at all times be inspected, and any part is accessible through a window. This arrangement is very similar to that adopted for synchronous converters, and goes a long way toward solving the noise problem.

The apparatus shown is primarily used in substations which are often located in residential districts or in the basements of large office buildings. Accordingly, the reduction of noise to a low amount is of great importance, but is subordinate to ventilation.

Considering first the enclosing covers necessary for the proper ventilation, Fig. 11 shows a standard 1000 kw., 900 r.p.m. motor generator set with d.c. machine left open and a.c. machine enclosed. Standard enclosing end bells are used on the outboard end of the motor. Due to the proximity of the two machines, it is not feasible to use this construction on the inboard end, for the a.c. machine would take the outgoing air from the d.c. machine which may be approximately 15 degrees hotter than the room temperature. The inboard end of the a.c. motor under this condition would be approximately 15 degrees hotter than the other end.

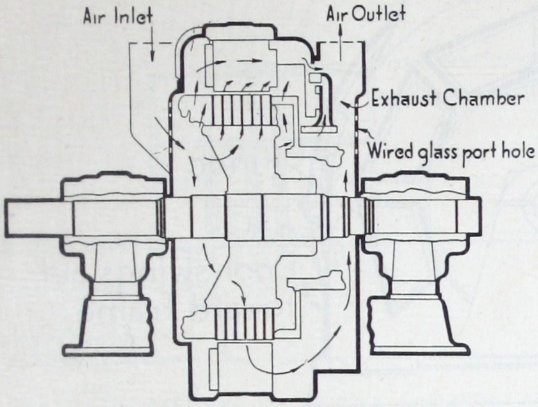


FIG. 10—D. C. GENERATOR TOTALLY ENCLOSED.

A double end bell, shown in Fig. 11, is placed on the inboard end and carried down to the floor plates. On the other end of the set the bedplate bridge is raised to permit the ventilating air to flow underneath. The air for the inboard end is then drawn from the room, under the bridge, and under the machine to the double end bell; thence through the machine to the room.

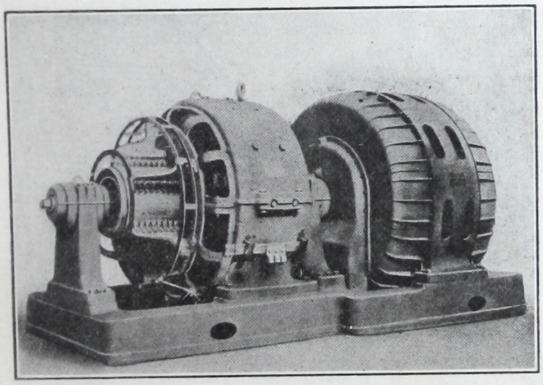


FIG. 11—MOTOR-GENERATOR SET—A.C. MACHINE ENCLOSED.

The motor rotor of a 1000 kw. set is a solid mass, with no possibility of passing air through. On larger sets with the units close together, the inboard end of the a.c. machine is completely closed, and the air from that end is drawn from the front through openings in the rotor.

### Synchronous Converters

Quite recently a design of enclosed synchronous converter, as shown in Fig. 12, was brought out which it is hoped will go a long way towards mitigating the difficulties of ventilating and suppressing noise in substations situated in congested districts.

The system of ventilation is in no way experimental, since the direction of the air through the machine has not been changed, but the air collected and discharged through a chimney similar to Fig. 13. The cooling air first passes over the collector rings and through the booster rotor and stator. The windage of the main armature is so strong relative to the booster armature that all the discharge from the small unit is carried into the main armature, and it is thus unnecessary to provide any enclosure over the collector rings. The first enclosure consists of an end bell extending down from the converter frame to the booster frame. The upper half of this end bell is cast in one piece and the lower half in two pieces for easy dismantling. Hand holes are provided for inspection and handling. This end bell catches all the air discharged from the rear end winding and directs it through the field and out into the front discharge chamber which extends around the commutator. The air passing through the armature core ducts and the front end windings also collects in the main discharge chamber.

This directional control of the ventilating air makes possible the efficient use of all the air passed through the machine and eliminates the defect of mixing incoming and exhaust air. Thus only the minimum quantity of air required for effective ventilation has to be handled.

The front enclosure cover consists of a circumferential cast bell in three parts. The top segment forms the hot air outlet to which the exhaust blowers are piped. The segments on either side of the converter commutator have large wire-glass doors, hinged for ready access to the brushes and brush-rigging. Windows are also provided on the front side of the enclosing end bell so that the view of the commutator is obstructed as little as possible.

The space for synchronous converters for location in office buildings is fixed by the building design, and capacities are constantly growing larger. The space limit for the required capacity of self-ventilated machines has been reached in many localities, and it is not improbable that forced ventilation will be used to obtain greater capacity from the same equipment. On synchronous converter work, it is frequently impossible to find adequate area for entrance ducts for forced ventilation in buildings where high ambient room temperatures are common.

One scheme of converter ventilation tried out by the Commonwealth Edison Company was that of placing a hood or housing like the scroll of a fan around the field frame, the object being to produce an action similar to that of a blower, the scroll corresponding to the housing of a fan and the armature to the wheel. This would have removed the objection found in the partition scheme by making the commutator and collector parts of the unit accessible. However, it did not reduce the temperature of the machine to any appreciable degree although it did cool the substation space. The presence of

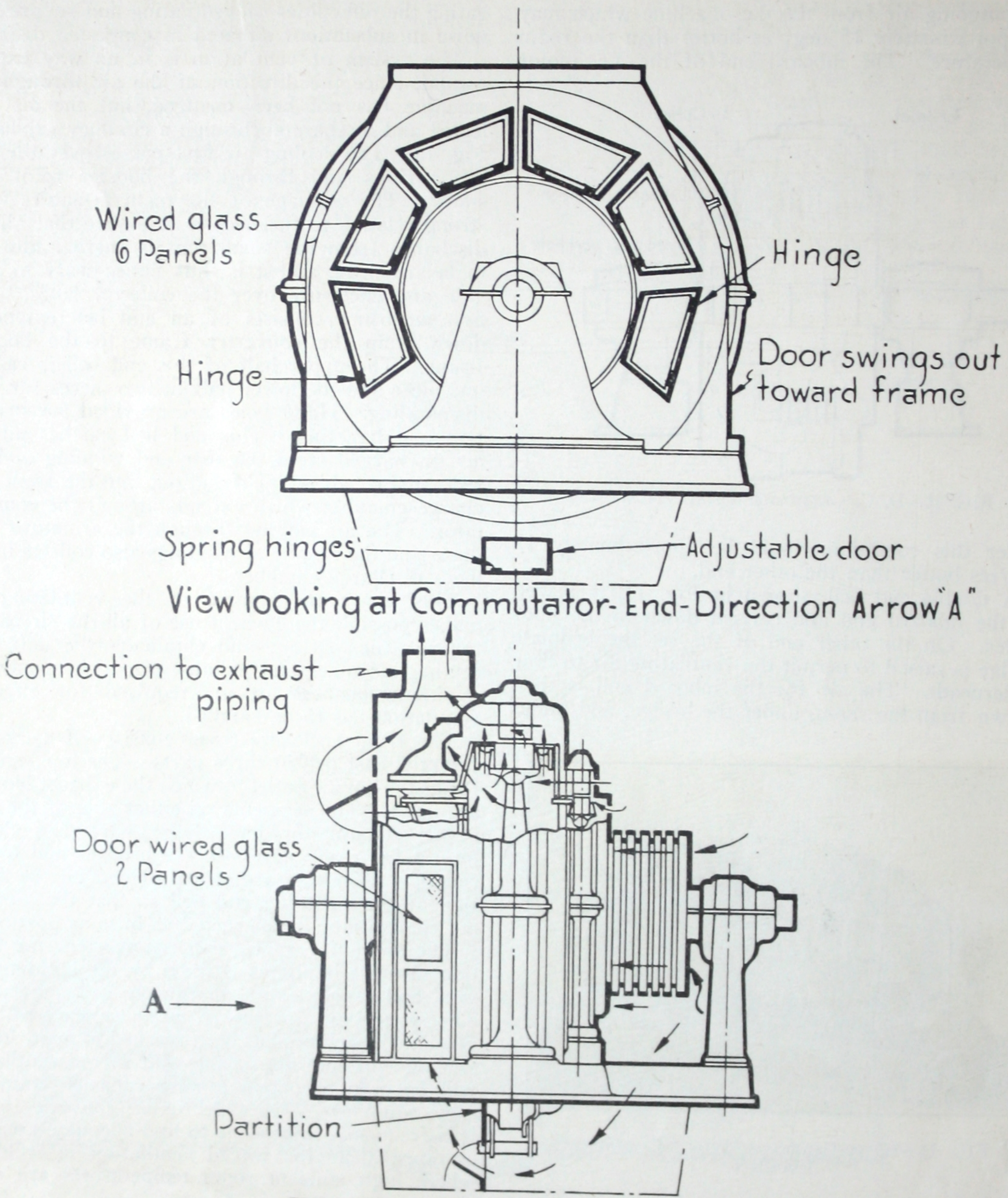

Wired glass
6 Panels
Hinge
Hinge
Door swings out toward frame
Spring hinges
Adjustable door
View looking at Commutator-End-Direction Arrow "A"
Connection to exhaust piping
Door wired glass
2 Panels
A
Partition

FIG. 12—ENCLOSED SYNCHRONOUS CONVERTER.

the field frame, windings and pole pieces within the housing caused sufficient eddy currents in the air as to nullify the blower characteristics and made the scheme of no value.

**Synchronous Condensers**

Synchronous condensers are often located in substations in residential or office districts where noise becomes an important factor. This apparatus does no mechanical work, and the tendency is to make them of high speed to reduce first cost and operating losses. While the peripheral speed of a condenser is much lower than a turbine, there is still a windage noise that is objectionable in a residential district. The larger types are made enclosed, regardless of their location, to obtain proper ventilation. The smaller types located in residential districts are enclosed to reduce the noise. Fig. 14 shows a 2000 kv-a., 720 r.p.m. synchronous condenser of the latter type. The enclosing arrangement is the same as that for turbo-generators. The air exhausts through the chimney top or through

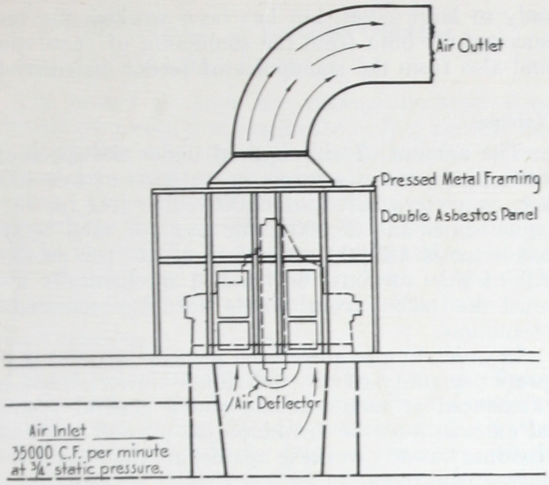


FIG. 13—HOUSING FOR SYNCHRONOUS CONVERTER TO ELIMINATE NOISE.

the bottom, and is then carried to the outside through a duct. Baffling plates are often placed in the duct to muffle the noise.

Many complaints have been received after installations of synchronous condensers. The noise is sometimes reduced by shrouding projecting bolts, covering spaces in the damper winding and making changes in the blowers, but mainly, the noise has been reduced to acceptable limits by taking the air to the outside through a baffled duct.

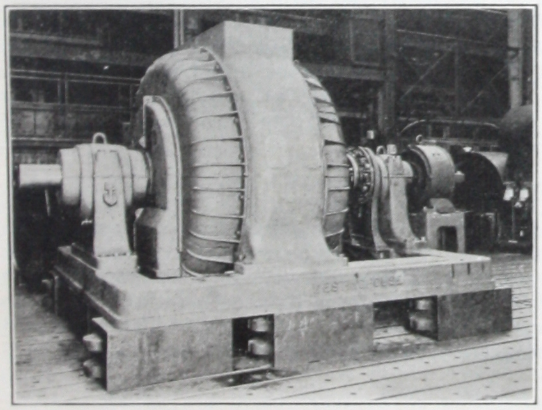


FIG. 14—ENCLOSED SYNCHRONOUS CONDENSER.

To eliminate the noise due to a 5000 kv-a. 12,800 volt synchronous condenser installed in a substation not designed for this apparatus the Union Gas & Electric Company, of Cincinnati overcame the undesirable feature by entirely enclosing the condenser in a separate room and discharging the air through the roof. In this particular case a discharge duct of sheet iron was used and each section of the duct was cushioned by a cork gasket.

## Induction Motors

Induction motors are very rarely built with enclosing covers. When of large size, they are of such slow speed that they are neither noisy nor of such long core length that they require special ventilation.

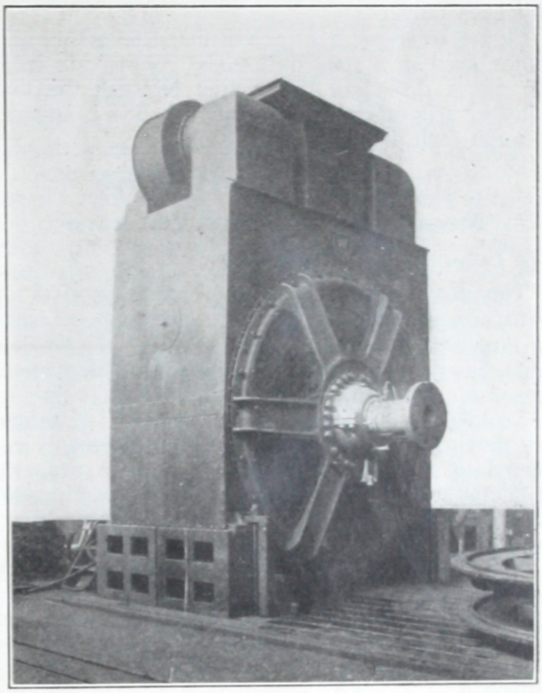


FIG. 15—ENCLOSED INDUCTION MOTOR—BATTLESHIP "TENNESSEE."

Figure 15 shows an enclosed induction motor of 7500 h.p., 175 r.p.m. installed on the battleship "Tennessee." The air for this motor is drawn from the main deck by separate blowers. It is then carried through the openings in the brackets and through the machine by the blowers mounted on the top casing, and then exhausted to a ventilating shaft leading to the deck.

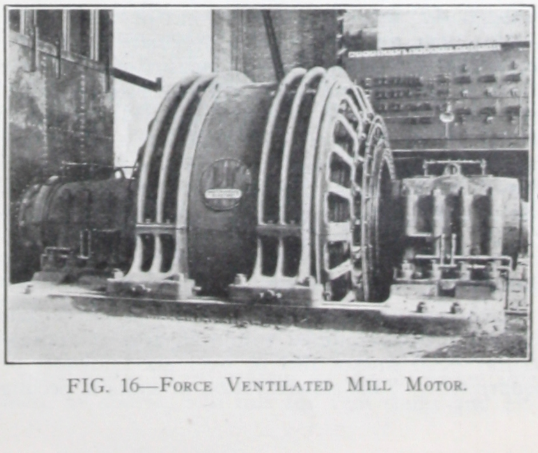


FIG. 16—FORCE VENTILATED MILL MOTOR.

### D. C. Machinery

Direct current machines are very rarely enclosed. Enclosing covers with separate fans are used for large reversing mill motors where the speed is so low that they will not self-ventilate properly. Motors for ship propulsion and generators forming parts of sets are sometimes enclosed by use of rear end bells only.

Figure 16 shows a force-ventilated reversing mill motor used in a steel mill. The cooling air from the pit is forced in the section between the two units by separate blowers, and then flows outward through each machine to the room.

## SUBSTATION VENTILATION

### Necessity for Mechanical Ventilation

#### Heat Losses Previously Determined

The demand for constantly increasing sizes of transformer and converter units within floor areas no larger than were formerly used for the smaller units, has resulted in the introduction of mechanical means for removing the excess heat.

To take care of the situation, mechanical means for moving the air, which have been commonly referred to as ventilation but which more properly speaking should be classed as air cooling equipment, have been designed where fans working under pressure are demanded.

The manufacturers of transformers and rotary converters are insisting upon a strict compliance with the specification requirements for air and find the requirements so far demanded are in some cases below the actual requirements which experience has indicated.

Since it is required to operate these machines at their full overload capacity for short periods of time, it is a matter of prime importance to install ventilating apparatus that will insure satisfactory results.

#### Confinement within Closed Walls

In congested districts where it becomes necessary to build between existing buildings, the substation structure demands making use of openings in the front, rear and roof only. If a one story structure were possible, natural ventilation might be obtained through sky lights in the roof, but property values are so high that it becomes necessary to build a three, four or even five-story structure, the converter room being on the first floor. The room in which the heat is liberated is therefore a closed box in which a very rapid rise in temperature would take place unless mechanical means for changing the air were liberally supplied. To prevent the mixture of the incoming and outgoing air, the ducts must be carried through the upper floors.

#### Concentration of Larger Units

In the large substations a capacity of 28,000 kilowatts has been confined within an area of approximately 4500 square feet or over six kilowatts per square foot. This concentration of units is peculiar only to large cities, but has been worked out very successfully both from the standpoint of ventilation and also from the standpoint of feeder distribution.

#### Volumes

The amount of air required under the specifications of the manufacturers in a station of five 4000 kw. converters based on 12,000 cubic feet for each transformer and 25,000 cubic feet for each rotary converter is 185,000 cubic feet of air per minute. All of this air must be handled mechanically and must be taken from points insuring reasonable cleanliness.

In order to guarantee each piece of apparatus its proper quantity of air, individual blowers must be introduced at each machine and a general system of exhaust must be introduced to prevent these individual blowers working against an abnormal pressure in the room.

### Admission of Air to Converter Room

#### Point of Admission

In selecting the point of admission for fresh air, care must be taken to avoid drawing any of the air over the sidewalk which is usually heavily laden with dust and such point must be remote from the point of discharge. Since in the City of New York the Building Code requires a set back in the building at the rear so that not more than 90 per cent of the area of the lot may be occupied at a height of 23 feet above the curb, an excellent opportunity is afforded to secure a source of fresh air at the rear of the building, the air being admitted from a point 23 feet above the curb and remote from the sidewalk where the air will probably be found as free from dust and dirt as it would be possible to secure.

#### Air Washers

In many of the designs of the recent stations it has been found possible to provide a space in the basement near the point of admission from the rear of sufficient size to introduce an air washer. No air washer, however, has as yet been introduced and the question is still being debated as to whether an air washer will be required at any time.

#### Provision Against Snow and Rain

On account of the high velocity of the incoming air, rain and snow are drawn in, and in extremely cold weather, snow is frequently drawn in to the nearest machine. To provide against this shutters are introduced in the air passageway which may be quickly closed, cutting off entirely or throttling the incoming air. At the bottom of the air intake a drain is provided connected directly to the sewer or a sump pit.

#### Velocity

An effort is made to so design the inlet that an average maximum velocity of 1200 feet per minute will be insured.

## Distribution of Exhaust Opening

### Movement of Air in Machine Room

The heated air from the various machines rises directly over each machine to the ceiling and the exhaust system must be so designed that this heated air can be picked out at various locations near the ceiling. Unless this be done, portions of the rooms, particularly those remote from the front openings, will be abnormally heated and the machines in the rear of the room will feel the effects of the high temperatures of the atmosphere of the room.

### Duct Construction

The air duct in the rear leading into the fresh air chamber in the basement prevents the installation of windows and the only natural opening to the outer atmosphere is in the front of the room, which in hot weather is kept opened by the station operators. If the exhaust system which is frequently taken up in the front of the building is not distributed over the entire area of the room by means of ducts, there is the short circuiting of air from the front doors and windows directly into the exhaust duct, thereby defeating the purpose of the exhaust.

### Interference of Ducts on Ceilings and Collapsible Ducts

The ducts that are carried over the ceiling of the converter room are made collapsible or removable wherever there are crane interferences. The exhaust duct passing up through the building to the blower pent house on the roof is built in with the masonry construction and plastered or finished smooth on the inside to reduce friction.

## Vent on Roof

### Annoyance to Neighbors

The warm air exhaust through the roof fans is in many cases discharged at points lower than the neighboring buildings and in the summer time when the windows are kept opened and the air is particularly warm, great care must be used to prevent annoyance to the neighbors. The exhaust must, therefore, be carried as nearly vertical as possible and located after carefully surveying the neighboring conditions.

Good results are often obtained by exhausting through holes in the roof without the introduction of pipes or ducts projecting above the roof. This removes the imaginary annoyance which the sight of an exhaust head might produce.

### Muffling of Exhaust Air

If the discharged air is delivered at a very high velocity, a very disagreeable noise is sometimes produced which annoys adjoining tenants, particularly at night time, and efforts have been made to provide a muffler which will not decrease efficiency.

Experiments made by lining the exhaust chamber with sound deadening brick or sound absorbing material have been made but results hardly warrant any great expense in this line. If the air be exhausted into a large chamber, which in turn vents to the roof through a steel grating, the sound is hardly audible except to one standing near the grating on the roof.

## Specific Cases

Investigations by the Commonwealth Edison Company over a period of five or six years indicated that while the problem is one of space ventilation, no solution was feasible without taking into consideration the ventilation of the apparatus; that is, the present type of converting apparatus required that the two problems be considered together. The problem is further complicated by the question of handling the intake and exhaust air, especially so when installing ducts in basement stations or carrying them to the top of business buildings. Further investigations also indicate that where sufficient space and openings overhead are available, the natural ventilation of machines, as now designed, is much to be preferred. In substations above the street level where the building structure permits large ventilating monitors in the roof over the row of units and both ends of the substation opened by means of large doors or windows, are superior to any wall baffles or ventilating partitions such as are necessary in substations located below the street level.

For substations below the street level, as in Chicago where the intake and discharge openings are on opposite sides of the room, approximately 60 per cent of the air was not affected in any way in cooling either space or apparatus. In other words, the air was drawn in from the intake, drifted across the ceiling and out the discharge duct. This interferes with the natural displacement of the room air rising from the units so that there was considerably more re-circulation of room air than in the substation with an open monitor. For correcting this condition, the best method was found to be by dividing the substation into two rooms by means of a partition or wall placed parallel to the row of units and so located that the commutator end of each machine just projected through the partition. This permitted all of the air drawn into the machine from the d.c. end to be taken directly from the fresh air intake and reduced the amount of re-circulation by approximately 60 per cent. These partitions were found to reduce the temperature of the air discharge over the machine approximately 10 deg. cent. on the average. This partition did not effect the usual amount of re-circulation of the air through the collector ring side of the main armature and through the booster armature. This re-circulation might be further reduced by the installation of another wall along the a.c. side of the units, but would seriously interfere with operating conditions and maintenance of apparatus. While this type of installation has not given entire satisfaction, it is thought to be the best obtainable with synchronous converters as now designed.

The conclusion has been reached that the ventilating problem for new machines can best be solved by providing a closed system on the discharge side which, of course, will call for vent ducts and exhausting fans; and further, that the intake air to the unit should be drawn from the open substation space rather than by means of an intake duct since a common intake duct to several machines does not give equal air distribution.

The Stone Street Substation of the New York Edison Company, now in the course of construction, is being built along what is believed to be the most approved lines, Figs. 17, 18 and 19 show the general scheme. In this building the scheme is to bring the fresh air in from the roof through a vertical shaft at a velocity of 900 feet per minute to a chamber under the rotary converters and air blast transformers, entering the chamber directly at the middle point, and in this chamber are located the blowers discharging directly upward into the converters and transformers.

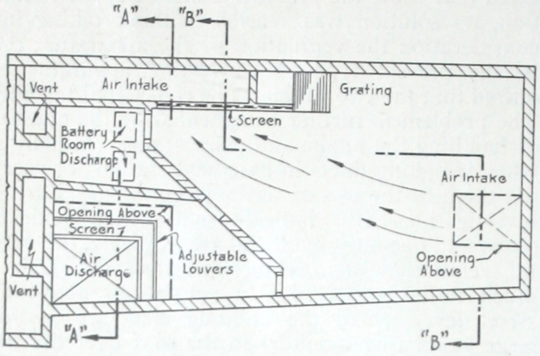


FIG. 17—N. Y. EDISON CO. STONE ST. SUBSTATION—HALF PLAN OF TOP FLOOR.

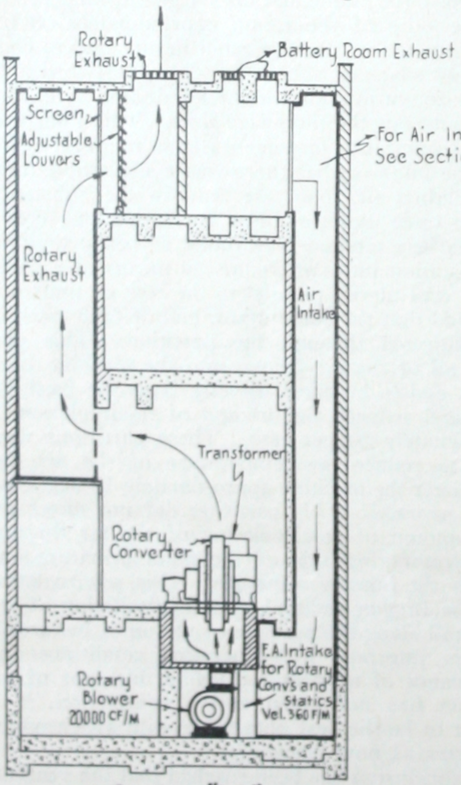


FIG. 18—N. Y. EDISON CO. STONE ST. SUBSTATION—AIR EXHAUST.

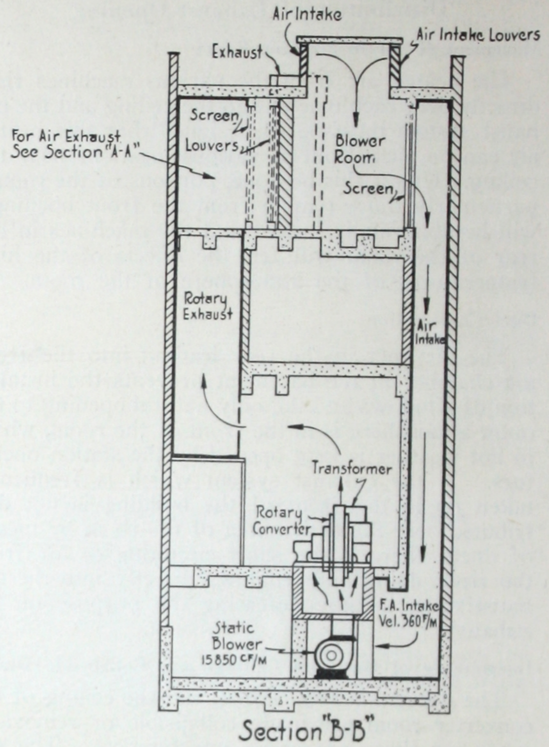


FIG. 19—N. Y. EDISON CO. STONE ST. SUBSTATION—AIR INTAKE.

The capacity of the converter is 4200 kw., and of its blower, 20,000 cubic feet per minute at 1 in. static pressure. The blower discharges freely under the converter but the cooling efficiency is rather indefinite due to the difficulty of discharging the cool air directly on the commutator. A sheet metal enclosure so designed as to direct more efficiently the discharge of air from the blower will form a part of the converter.

From several substations where ventilating partitions have been installed handling air in amounts varying from 30,000 to 50,000 cubic feet, due to variation in general station load, the conclusion has been drawn that each installation to a certain extent must be treated individually.

Figs. 20, 21 and 22 are views of the rotary converters, air blast transformers and ventilating blowers in the New York Edison Company's East 6th Street Substation.

Fig. 20 shows a line of blowers located immediately underneath the converters. The fresh air is taken in from a rear air shaft through ventilating louvers. On the left-hand side of this view is shown a concrete wall which separates the converter blowers from the transformer blowers. The trans-

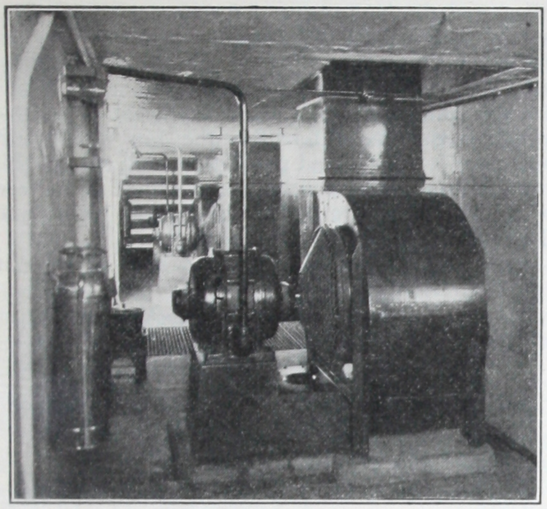


FIG. 20—N. Y. EDISON CO. E. 6TH ST. SUBSTATION—VENTILATING BLOWERS.

former blowers are in practically the same position as the converter blowers.

Figs. 21 and 22 are views of the machines ventilated by these blowers. The discharge is into the open room which is in turn sucked up through an opening in the ceiling by blowers above to be discharged into the open at the roof.

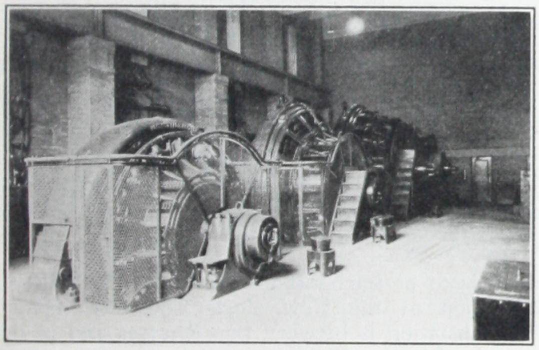


FIG. 21—N. Y. EDISON CO. E. 6TH ST. SUBSTATION—SYNCHRONOUS CONVERTERS.

### Basement Substations

Ventilation of basement type of substations of today has become of great importance due to the difficulty of not only getting air to the substation for room ventilation but also the difficulty of directing the air through the machines effectively and to get sufficient outlet for the amount of air required.

The Commonwealth Edison Company has done some experimental work along the lines of enclosures for apparatus; also expensive enclosures of the partition type which virtually encloses machines in a separate room have been built, but results indicate that the only satisfactory answer to this problem from a new apparatus point of view is to have the manufacturer enclose the machines in a manner similar to that which they have followed in connection with synchronous condensers. There may be some limitations to this method as regards commutators on account of the machines being placed on a basement floor instead of having a basement beneath, and there may be some other objections due to apparent inacessibility which only operating experience can measure. In the cases where machines have been enclosed with a partition, air is drawn through the commutator which projects through the partition and a suction is maintained behind the partition to pull the heated air away from the machine into the exhaust duct. This type of construction applies, of course, where the machines are in a row with shafts parallel and is a possible solution for the older types of machines.

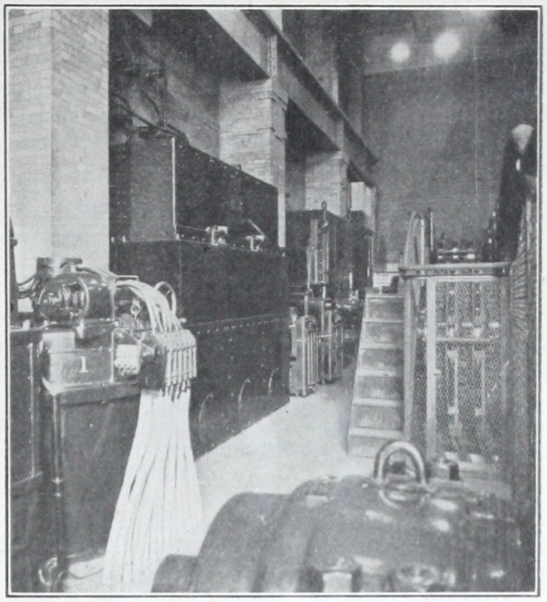


FIG 22—N. Y. EDISON CO. E. 6TH ST. SUBSTATION—AIR BLAST TRANSFORMERS.

### Battery Room Ventilation

The ventilation of a storage battery room is similar in many respects to the general ventilation of the rotary room or any other large room. The question of the number of air changes per hour must be determined by experience after observing the effects of a rapid charging or discharging of battery.

The principal problem in the ventilation of a battery room is to destroy the acid fumes before they are discharged into the atmosphere. The average substation in New York City is lower than the surrounding buildings and the acid fumes therefore must very readily find their way into neighboring apartments. In spite of all the efforts that have been made to destroy these fumes, it is practically impossible to obtain 100 per cent perfection. This, however, is really not essential because the dilution of the acid laden air by the atmosphere is sufficient to destroy a large percent of the acid which is drawn out through the ventilation system.

The elimination of a high percentage of the acid would naturally be followed by a very low efficiency of the ventilation system and a line must be drawn somewhere if ventilation is to be sufficiently effective to prevent the accumulation of acid and free hydrogen in the battery room.

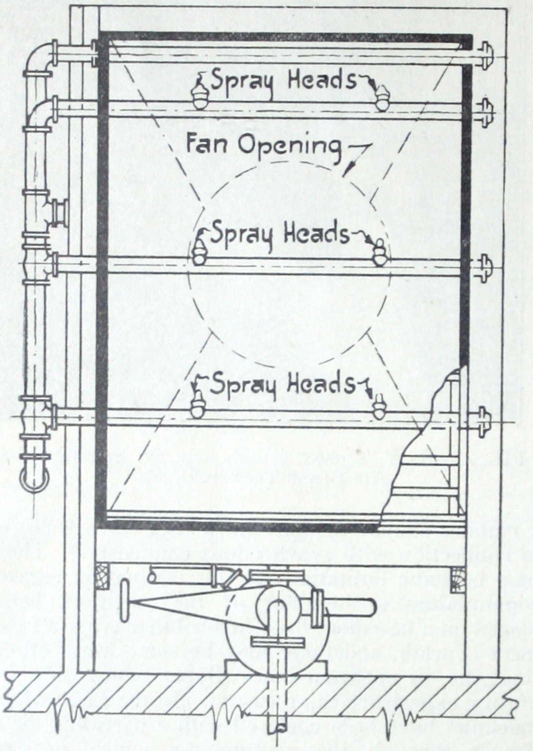


FIG. 23—N. Y. EDISON CO. W. 39TH ST. SUBSTATION—CROSS SECTION OF ACID ELIMINATOR.

Various forms of acid eliminators have been designed with more or less success. The introduction of a soda solution through which the acid fumes pass has shown that very little neutralization takes place and the best results have been obtained by a spray washer with fresh water and the standard form of eliminator plates. The acid eliminator must be introduced between the battery room and the fan, and even with the small percentage of acid which passes the eliminator, the fan rapidly deteriorates. A good acid proof paint will correct this trouble, but better results are obtained by a lead wash over the entire surface of the fan blades and the inside surface of the metal duct.

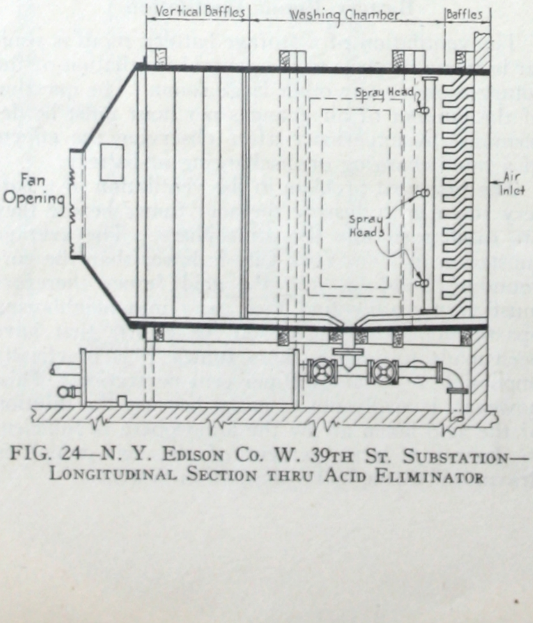


FIG. 24—N. Y. EDISON CO. W. 39TH ST. SUBSTATION—LONGITUDINAL SECTION THRU ACID ELIMINATOR

Figs. 23, 24 and 25 show an acid eliminator which is to be introduced in the West 39th Street Substation of the New York Edison Company. This substation is between two theatres and in the rear of a 24-story building, so it is of great importance to prevent the distribution of acid fumes. This washer will replace one made up of perforated lead plates without a spray, which has not been satisfactory.

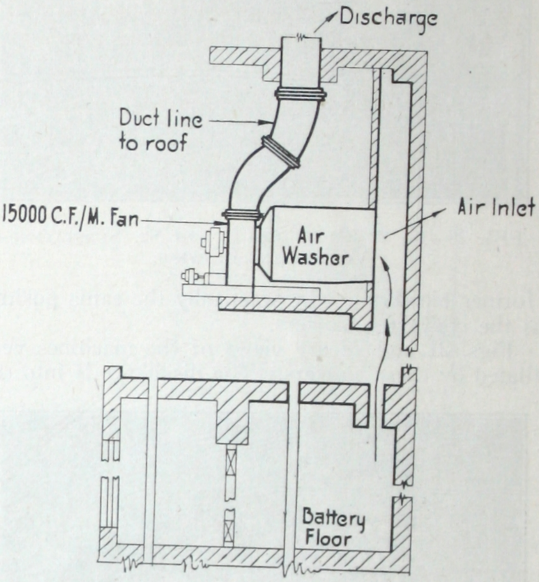


FIG. 25—N. Y. EDISON CO. W. 39TH ST. SUBSTATION—SECTION SHOWING ACID ELIMINATOR OR AIR WASHER IN POSITION.

A new type of blower introduced this year by the New York Edison Company in which the inside surfaces have been treated with a rubber composition applied in a layer about 1/8 in. thick. These special fans have not been in service long enough to give any definite results.

The spray washer or any other form of washer which requires the use of water necessitates the introduction of water service at the roof line and an acid proof drainage system. This means, in many cases, the introduction of a pump and a tank in order to maintain water at the roof level.

In order to make the movement of air through the battery room uniform, registers are introduced at the opposite end of the room to the exhaust. These registers are placed along the floor line and also at the ceiling line so that the room becomes a ventilating duct across its full cross section with fresh air being forced along the floor which would otherwise remain quite damp.

The exhaust from this system should, as in the case of the converter room ventilation, be projected vertically upwards which will conduct the diluted acid laden air to a higher atmosphere and permit of further dilution before it could be carried to neighboring windows.

On account of friction through the eliminator, it has been found good practice to supply an exhaust fan of a capacity that would empty the room about fifteen times per hour with free exhaust. The net result could possibly be reduced on account of this friction to ten times per hour.

### Temperature Data from Operating Companies

The principal consideration seems to be to prevent room temperature from exceeding the point at which operators can comfortably work and to prevent apparatus from operating at a temperature above its guaranteed limits. Due to the wide variety of construction obtaining in substation buildings, it would seem that each proposition must be approached individually as it is evident that substations located in outlying sections can be so designed as to preserve comfortable and safe temperatures with natural ventilation, whereas substations in the basements of downtown buildings would require artifical ventilation, the size and type being dependent upon space available, arrangement and capacity of installed apparatus.

TABLE II

SUMMARY OF REPLIES TO QUESTIONNAIRES RELATIVE TO SUBSTATION ROOM AND APPARATUS TEMPERATURES

| | Approximate Average Room Temperature | Approximate Maximum Apparatus Temperature |
|---|---|---|
| Boston Edison Co. ....... | 37° | Guaranteed Limit |
| Brooklyn Edison Co. ..... | 40° C. | Not given |
| Commonwealth Edison Co.. | 51.5° | 85° New Equip.<br>80° Old Equip. |
| Consumers Power Co. .... | Regulated for Operator's Comfort | Within Reasonable Limits |
| Detroit Edison Co. ...... | 35° | 70° |
| Kansas City Pwr. & Lt. Co. | 41° | Not given |
| Louisville Gas & Elec. Co... | 38° | 80° |
| Milwaukee Elec.Ry. & L.Co. | 40° | 80° |
| Mississippi River Pwr. Co. | Within few degrees of summer outdoor temperature | Manufacturer's Guarantee |
| Montreal Lt., Heat & Pr.Co. | 38° | Not given |
| Narragansett Elec. Lt. Co.. | 35° | 60° |
| New York Edison Co. .... | 10% above maximum summer temperature | 80° |
| Public Service Elec. Co... | 35° | 85° |
| Rochester Gas & Elec. Corp. | 32° | 85° |
| San Joaquin Lt & Pr. Co... | High temperature—No attempt to regulate | All Transformers Outdoors |
| Southern Sierra Power Co.. | 45° | 74° |
| Union Elec. Lt. & Pr. Co... | 45° | 85° |
| United Elec. Lt. & Pwr. Co. | 36° | Manufacturer's Guarantee |

Sufficient data is not now available to enable us to formulate any standards, for temperatures will involve a classification of different types of substations containing different types and sizes of electrical equipment.

### Ventilation Tests

Some very interesting tests on natural ventilation of substation equipment have been made by the Cleveland Railway Company. The station tested was a railway substation with automatic control in which were installed two 1500 kw. synchronous converters with air blast transformers and automatic switching equipment.

The tests were conducted with smoke obtained from a device similar to that used for smoking bees. This smoke was blown into the ventilating air at different points and the course of the air current carefully charted. The accompanying illustrations show the results obtained.

Fig. 26 shows a longitudinal section of the station. There is a ventilating chamber extending the entire length of the basement which opens to the outside atmosphere at each end. It was intended that cool air should blow in at both ends of the duct, rising up through the openings in the bed plate of the machines and then out the roof ventilators. As the chart shows, the air does not move in the direction expected. The cool air flows in through the ventilators at the right hand end of the station, and part of this air flows directly through the ventilating chamber and out the opposite end. Fig. 27 is a cross section of the station which shows the re-circulation of a portion of the air and also that hot air from the discharge of the air blast transformer flows into the converter instead of rising directly to the ceiling and out the roof ventilators as expected. There is also shown some re-circulation of the air coming out of the transformers and back through the blower into the pressure chambers.

Fig. 28, a plan view of the basement, shows how the flow of air enters at one end and proceeds quite consistently toward the opposite end, all going out the opposite ventilator instead of rising through the floor openings. These tests would seem to prove that the modern tendency toward separation of intake and discharge air is the correct method for securing good ventilation of rotating apparatus.

Careful tests have been made by the Commonwealth Edison Company on the experimental hood Figs. 29 and 30, installed over Unit 1 at Plymouth Place and are comparable with similar tests made on Unit 2, which is the same type of machine but has no hood over it.

The design of the machine is such that both ends of the armature and the end of the commutator carry a swirl of air around with them as they rotate. This air enters between the risers to the armature

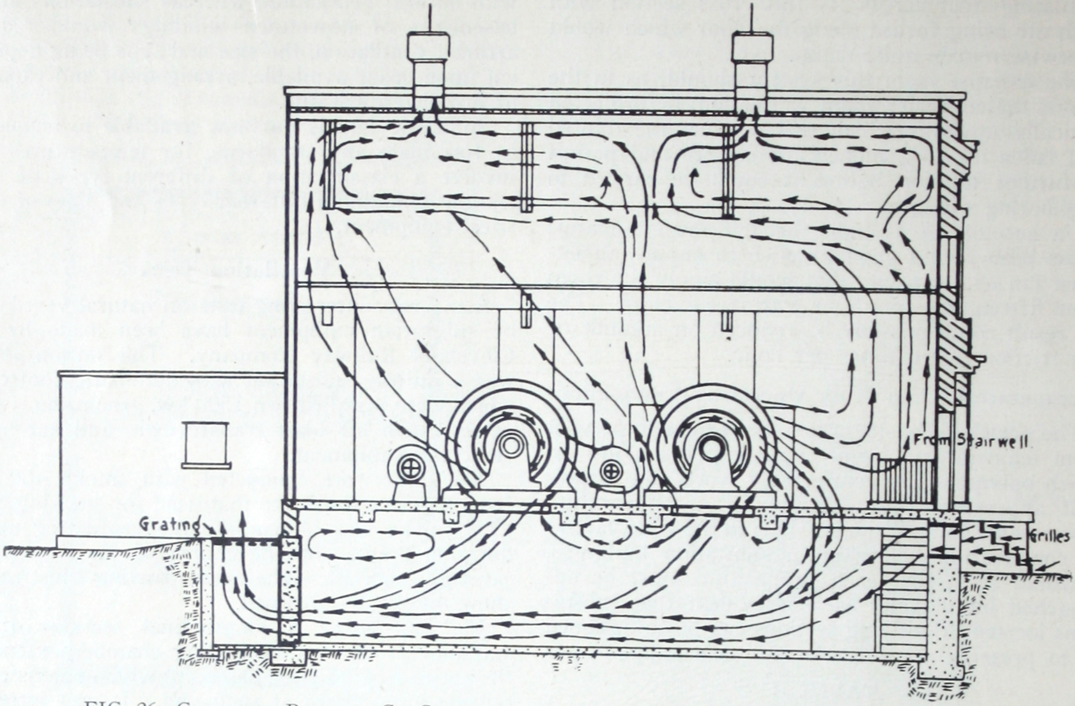


FIG. 26—CLEVELAND RAILWAY CO. SUBSTATION. AUTOMATIC CONTROL—LONGITUDINAL SECTION.

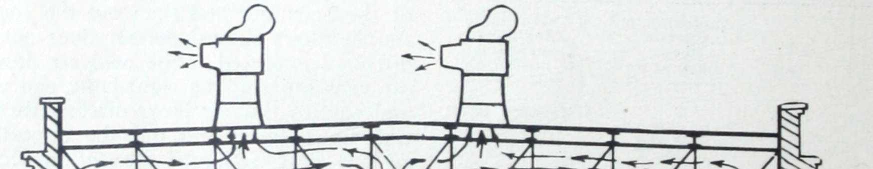


FIG. 27—CLEVELAND RAILWAY CO. SUBSTATION. AUTOMATIC CONTROL—CROSS SECTION.

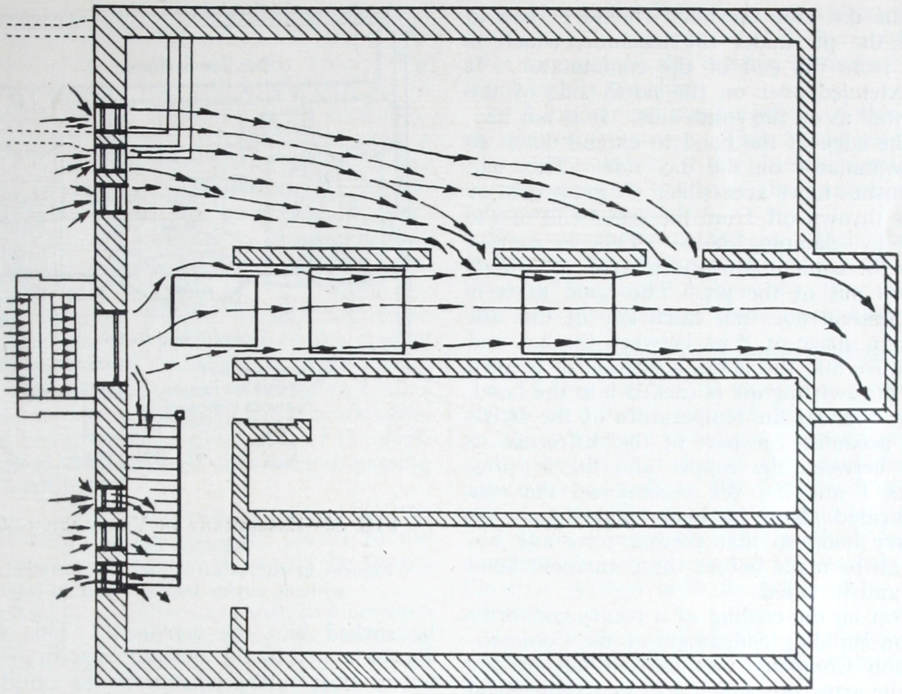


FIG. 28—Cleveland Railway Co. Substation. Automatic Control—Plan of Basement.

and is then thown out again, some of it passing off and part mixing with new air and being sucked into the machine again. About two-thirds of it is re-circulated air and about one-third is cool air. At full load the difference in temperature between this swirl and the air passing out from the machine is 4 deg. cent. on the machine with the hood, and 3 deg. cent. on the machine without the hood. An all day run at full load indicated that the temperature of the copper of the armature was 10 degrees hotter than the swirling air on Unit 1 and 7 degrees hotter on Unit 2.

When the hoods are installed on all of the units and the partitions separating the room in two parts are in place, the room temperature will be lower by about 15 or 20 degrees. This could not be accomplished by hoods made like the present experimental hood because it is not large enough and allows a great deal of heated air to pass out into the room and re-circulate through the machine. The hood should be about 6 in. deeper on the south side, and should be 2 in. from the armature on the a.c. end, and flare out 2 in. wider where it passes the field

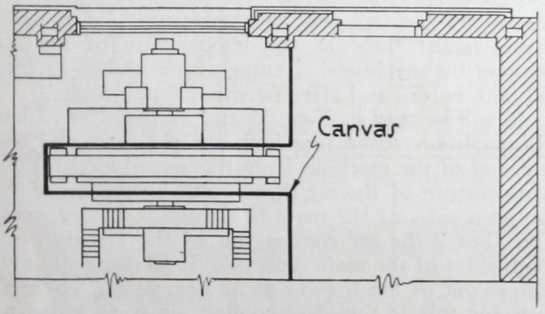


FIG. 29—Experimental Ventilating Hood for Synchronous Converter.

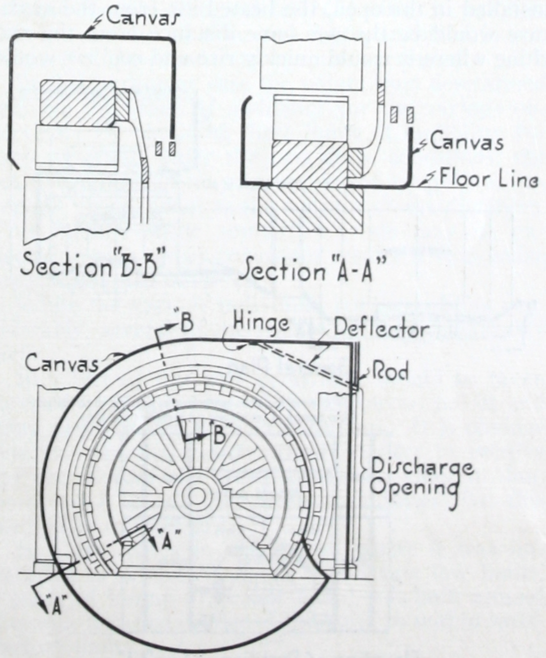
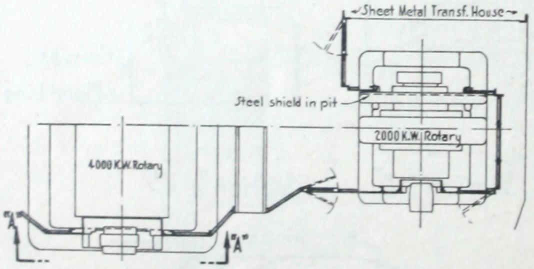


FIG. 30—Experimental Ventilating Hood for Synchronous Converter.

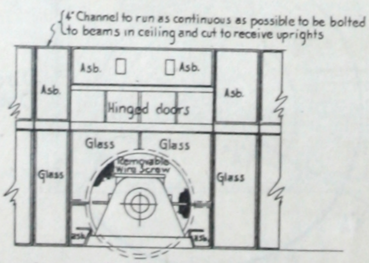
yoke. On the d.c. side the hood should extend to the edge of the pit under the machine, which is about 6 in. from the end of the commutator. It should be extended over on the north side of the machine as well as on the south side. It is not necessary for the edge of the hood to extend down so near the commutator on the d.c. side. This will make the brushes more accessible. A great deal of heated air is thrown off from the outer end of the commutator by clamping bolts. This is carried around with the commutator and a large volume of air is thrown out of the pit. The hood as it is installed at present does not catch any of this air.

By leaving a space of 2 in. between the a.c. end of the armature and the hood, a suction is formed and part of the swirling air is sucked into the hood. This actually reduces the temperature of the swirling air and accounts for part of the difference in temperature between the copper and the swirling air on Units 1 and 2. We recommend that the changes indicated above be made immediately on the temporary hood so that further tests and observations can be made before the permanent hood is designed and installed.

Another test on the cooling of a rotary converter at the Edison Building Substation of the Commonwealth Edison Company was carried out by the rotation of the armature which acts as a centrifugal blower, sucking the air in through the ends and blowing it out through the ventilating ducts in the core and end connections of the winding. The peripheral speed of the surface of the armature is such that air is blown through it at a velocity of 5000 feet per minute, which is equivalent to nearly one ounce of static pressure. If the machine were installed in the open, the heated air from the armature would be thrown some distance from the machine where it would quickly rise and cool air would be sucked into the armature. This condition is approximated by the substations with monitor roofs, but in most of the substations the ventilation is not upward but horizontal across the room. The cooling air enters at one side of the room, passes across the room and out the other side through either windows or a duct. If half of the air sweeping across the room passes through the machines and half over them, then the temperature of the air entering the machines will be the same as that at the exhaust, and the temperature of the air leaving the machines will be much higher. On the other hand, if we separate the cooling air from the heated air, as shown in the accompanying print, the heated air will pass out of the exhaust at the same temperature that it leaves the machine. This would be the same as the temperature that enters the machine in the case mentioned above.



General Plan


4" Channel to run as continuous as possible to be bolted to beams in ceiling and cut to receive uprights
Asb.
Asb.
Asb.
Asb.
Hinged doors
Glass
Glass
Glass
Glass
Removable Wire Screw
asb.
asb.

Elevation of Partition on Line "A-A"

FIG. 31—PARTITIONS FOR SYNCHRONOUS CONVERTERS, EDISON BUILDING SUBSTATION OF COMMONWEALTH EDISON CO.

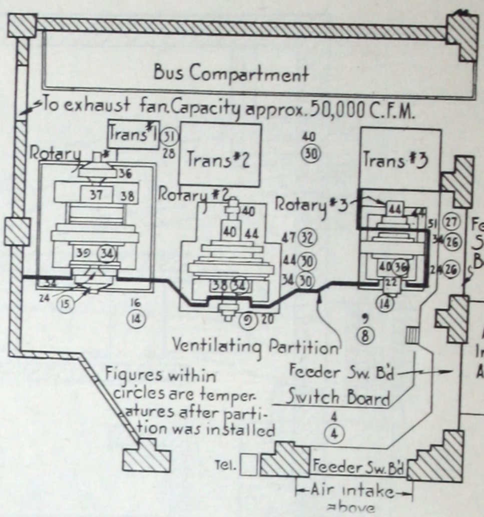


FIG. 32—EXPERIMENT IN VENTILATION—COMMONWEALTH EDISON CO.

Figures in circles after partition installed. Figures without circles before partition installed.

Fig. 31 shows the location of the temporary partitions installed at the Edison Building Substation to separate the cooling air from the heated air. Insufficient ventilation is provided by the exhaust fan and part of the heated air is re-circulated by the machine, but none of the cooling air passes over the machines directly to the exhaust. This is shown by the fact that the temperature at the exhaust is the same as the temperature of the air leaving the machines. Temperatures shown in Fig. 32 both before and after partition was installed.

It will be seen in Figs. 31 and 32 that Unit 3 has the partition separating both the d.c. end and the a.c. end of the machine from the heated air, and the temperature of the air thrown out by the armature on both sides of the main field yoke is 26 deg. cent. On Unit 2 the air coming out of the armature on both sides of the main field yoke is 30 deg cent., and comes out of the booster at 32 deg. cent. The reason for this is that less cooling air is provided at the a.c. end of the armature and so heated air is re-circulated to some extent.

Asbestos barriers are being installed on all three units where the air enters the a.c. end of the armature. This will prevent the heated air from being drawn into the machine and will allow cool air to be sucked over to the a.c. end through the commutator spider. As soon as these barriers are in place a test will be made to show the effectiveness of this scheme. The advantage of these barriers is that they will make it necessary to provide two partitions, one to direct the cool air to the d.c. end of the machine and the other to direct it to the a.c. end of the machine.

Previous to installing the partition, it was especially hot around Units 1 and 3; all of the cooling air swept around Unit 2, much of it passing over the machine and not through it, so that even Unit 2 did not run as cool as it now does with the partition in place. This shows that a great deal of the cooling air passed into the exhaust duct without passing through the machine.

On Unit 2 (being the center machine of the group), additional fan blades were placed in the commutator spider that more air would be drawn in from the commutator side.

Sheet metal rings or collars are installed between partition and fiber guard, enclosing the radiating fins at end of commutator to prevent hot air of commutator from being drawn into spider.

## NOISE

While considerable is heard about prevention of noises in substations, no great amount of work seems to have been done along these lines, except in a few cases. For instance (as thoroughly described in the *General Electric Review* of October, 1922—article on Garvanza Noiseless Substation of the Los Angeles Railway Corporation), it is almost universally true that in stations not fundamentally designed to be noiseless, satisfactory relief has been found by enclosing the offending piece of machinery in a separate room and discharging its air through the roof. Likewise, improved methods of machine ventilation such as ducts and partitions seem to help materially.

### Determination of Noise

Continuous complaints to companies operating substations in closely congested or residential districts have required in some instances that specific attention be given to its reduction or elimination.

Several methods for the determination of the magnitude of the offending noise as well as for the percentage of suppression due to several methods introduced are:

1. An electrostatic transmitter in conjunction with amplifiers, a thermo-couple and a milliameter.
2. A carbon microphone, with amplifiers and an oscillograph. The measure of the sound intensity would be determined by the relative amplitude of the r.m.s. values of the current computed from the oscillograms.
3. A michrophone with amplifiers, a set of head phones and a "noise standard," commonly used by telephone engineers. The "noise standard" is adjustable and is fitted with a calibrated dial. By tuning the "noise standard" to the amplified noise, some measure of the relative intensity for different conditions is possible.
4. A mechanical diaphragm tuned to resonate with the desired frequency. This would necessitate delicate measurements of the physical amplitude of the vibrations and a study of the mechanical damping factor of the apparatus.
5. A physiological test in which the observers walk away from the source of the noise in a straight line until they are confident that they can no longer hear any disturbances from a particular source.

### Criticisms of Proposed Methods

1. If this method of providing sensitive instruments is utilized and all reasonable precautions in taking data are observed, it should give quite accurate results, but due to the sensitiveness of the apparatus as well as the likelihood of errors resulting, a simpler method seems to be preferred.
2. It is thought that this method, besides being cumbersome, would not yield as accurate results as the first method with its presumably inherent inaccuracies.
3. In this case it is felt that the change in intensity to the ear with different frequencies might introduce many errors.
4. Delicacy again enters as a prominent factor and probably this method would not be satisfactory as compared to simpler methods.

### Specific Cases

After consideration of the five different methods, the Public Service Electric Company of New Jersey selected the physiological test (5) since it was felt that the amount of time and money involved in one or more of the other tests was not warranted.

In this particular case the points thus determined indicate the limits of audibility for the various observers. By obtaining these limits of audibility for each observer under the two noise conditions, the relative reduction may be expressed roughly as inversely proportional to the squares of the distances. This method while somewhat crude may be expected to give rather consistent results if reasonable precautions are observed.

While the various individual readings differ considerably, several of the results checked remarkably well.

In a test of this sort great care should be taken to conduct it at a time when extraneous noises and wind disturbances are at a minimum. It is obvious that the personal equation with respect to relative ear sensitivities and sound reflections enter in, but, however, it is felt for ordinary purposes that this method is satisfactory.

In a few cases in substations where it was imperative to reduce the noise to extreme low limits, a room of burlap or beaver board was built around the unit, and this deadened the noise to within satisfactory limits.

The case of a 1000 kw. 900 r.p.m. motor generator installed by the Public Service Electric Company in its Fort Lee Substation, not designed to accommodate anything but static apparatus, caused so much vibration and noise that a remedy had to be found. The vibration was eliminated by rebalancing. As an experiment, in order to lessen the noise, a tile wall was built across the rear of the substation to replace a sheet iron end that acted as sounding board. In addition, a 10,000 cubic foot blower was installed in the basement to force air through the machine over which was built a double sided wooden housing. The air passed through the motor-generator set going to the roof, then downward to the floor, through the double sides and into the room. It is judged that this housing eliminated about 60 per cent of the noise, but which was not enough to stop complaints.

One objection to the housing was that it offered so much resistance to the air that the motor generator set became so heated it was considered unsafe to more than nearly approach its maximum load, and in hot weather the load was limited to considerably below normal rating.

Last year the company installed at Bayonne, N. J., another machine of the same size and make, which was so noisy that the building was finally closed tight by means of double windows and double doors. In addition, exhaust blowers were installed in the roof with a baffle arrangement between the roof trusses and the gable of the roof. This installation eliminated a great deal of the noise and further changes will be made before long, but just how, has not been decided upon.

At the present time a new substation is being designed for the Public Service Electric Company to house two 1500 kw., 600 r.p.m. automatic motor generator sets for railway service and in addition there will be installed a number of 3-phase, 4000 volt, 4-wire automatic lighting and power feeders.

The building will be about 60 feet wide and 100 feet deep without windows. The air for ventilating the equipment will be taken through a duct in the roof and forced through the motor generator set by means of a blower. The heated air will rise to the roof where it will pass out through ventilators. The foundations for the motor generator sets will be built independently from the floors and the building walls and it is barely possible that several inches of resilient material will be put under the motor generator sets so as to act as a cushion. Additional precautions are not thought necessary but the building will be laid out in such a way that in case of trouble, due to the noise, the inside walls can be covered with some kind of a sound deadener.

In Rochester, N. Y., a new Edison substation with two 1800 kw. motor generator sets will be located adjacent to a school of music and steps are being taken to secure the quietest possible operation. Plans are not yet completely formulated, but in general it is aimed to build the station with walls a few inches from the property line and have the machine foundations separate from the walls to eliminate vibration. The air intake will be through a suitable filter either from the rear of the station or through the roof and the air outlet also will be through the roof through suitable baffle plates.

## RADIATOR TYPE COOLERS

The question of the use of radiator type coolers for removing the heat from the ventilating air in electric machinery has recently become active, and a few general remarks may be considered along lines touching upon design, advantages, possibilities, equipment, and general conclusions.

### Design

A surface cooler is a device similar to an automobile radiator, with air passing over one side and water on the other side of a number of tubes. The heat transfer from air to water can be effected if the device is supplied with the necessary amount of water at a temperature below the temperature of the air. The cooled air can never be brought down to the water temperature except by an infinitely long contact of the air with the elements of the cooler. In practice, if the difference in temperature between the hot air and the cold water be taken as 100 per cent, it is not practical to reduce the air temperature an amount in excess of from 55 to 75 per cent, depending on circumstances. The depth of the cooler in the direction of the air flow varies as the log $\frac{1}{1-x}$ where x is the per cent drop or change in air temperature.

### Advantages

The radiator type of cooler lends itself to the use of the closed air system of cooling. The hot air is taken from the machine, passed through the cooler, and sent back again into the machine. Such a system eliminates the possibility of carrying large volumes of dirt into the machine as now occurs with the open type cooling systems. The present open type system, when a washer is employed, removes the major part of the dirt, but, nevertheless, with the enormous volumes of air, some dirt passes the washer. The closed system also eliminates, to a large extent, the possibility of moisture being carried into the generator. Possibly a better assurance of moisture elimination is obtained if a surface cooler is employed in place of a wet filter. The closed system shortens up the air ducts and simplifies the station layout. There is also some advantage in the elimination of fire hazard, as the burning of insulation, if started, is choked down, due to the exhaustion of the oxygen in the closed circuit. The station noise will, in general, be reduced, as there is no direct communication between the air from the alternator and the outside air. When salt water is the only medium available for cooling, a wet filter is not possible, but a surface cooler can be used.

### Possibilities

The factors involved in the design of the cooler are: the losses to be handled; volume of air; the value of the temperature rise of the air leaving the cooler; temperature of the cooling water; and the permissible pressure drop through the cooler for the air circuit. The relation of these factors can be best shown by an illustration; viz., A may be taken as the change in the air temperature produced by picking up the losses in the generator. A, therefore is a fixed amount when the volume of air and the losses are known. B may be taken as the temperature of the air leaving the cooler. A plus B is, therefore, the temperature of the hot air entering the cooler, and can be taken as K. Let Q be taken as the temperature of the cooling water. K minus Q is the difference in temperature between the hot air and the cooling water. The cooler can reduce the air a percentage of this difference. Call this percentage x, and the difference T; then the air temperature change, in passing through the cooler, is Tx. B minus Q is a limiting factor in the cooler design, and the smaller its actual value, the larger the cooler. As a consequence, if the value B is set, and the accepted figure for B is 40 deg. cent., then the temperature of the cooling water is a vital factor, and consequently, the use of condensate as a cooling medium materially affects the design and cost of a cooler. First, because at light loads the amount of condensate available is insufficient for handling the no-load losses, and second, because with vacuums much below 29 in. of mercury, the temperature of the condensate is too high to absorb all of the heat at full load, with a reasonable design of cooler.

When using condensate, under light load conditions, several possibilities exist. One is to re-circulate the condensate and flash the temperature down in the condenser, supplementing the amount of condensate by using a storage tank. Such a system is possible but has the disadvantage that the storage tank in the circuit must be maintained under vacuum, and also considerable complication is introduced into the control of the water supply and the pump arrangement. A second arrangement is the use of two cooler elements, one employing condensate and the other cold water. The air coming into contact with the condensate element first, and giving up a portion of its heat. A regulating device can be fitted to the water supply of the cold water element so that it can be controlled and as much energy diverted to the condensate as will be permitted by limiting the entering air temperature to the generator.

The factors involved are as follows:

Let A be the change in air temperature, due to absorbing the machine losses. Let B be the temperature of the air leading to the generator. Then A plus B is the temperature of the hot air leaving the generator. Let $Q_1$ be the temperature of the condensate. Let $Q_2$ be the temperature of the cold water. Let $T_1$ be the difference in temperature between the condensate and the hot air, and $T_2$ the difference in temperature between the air leaving the condensate element of the cooler and the cold water. Let $zT_1$ be the change in air due to passing through the condensate element, and $xT_2$ the change in air in passing through the cold water element. Let $\%KW_1$ be the per cent of loss absorbed by the condensate element of the cooler.

$$\%KW_1 = \frac{T_1}{A} - Z \qquad (1)$$

$$\text{Also } K-Q_2 = \frac{1}{x}(K-B)\,(1-\%KW_1 x \%KW_1) \qquad (2)$$

Equation (1) permits us to determine the percentage of energy diverted to the condensate, when we control the water valve on the cold water element, so as to hold the air entering the generator at some predetermined figure. Equation (2) shows the limiting value for $Q_2$ under the conditions of Equation (1). An illustrated example will best show these conditions.

Assume that we have 800 kw. losses at full load, and 650 kw. losses at no load, with an air volume of 60,000 cubic feet per minute. Let us consider the case where it is necessary for the cold water element to handle the no-load losses with a maximum tmperature of entering air to the generator of 43 deg. cent. when the cold water temperature is 27 deg. cent. (80 deg. fahr.). The temperature rise in the air, due to the losses, can be estimated on the basis that 1 kw. loss will raise the temperature of 1800 cubic feet of air 1 deg. cent. per minute. Under the conditions given, the leaving air can be 16 degrees higher than the cooling water and the change in air temperature is 19½ degrees. The drop x is, therefore, 55 per cent. Let us use 0.60 in order to insure some margin in the cooler side. Let us further assume that the condensate element can be so proportioned that its factor z has a value of 0.50. Then, under full load conditions, the cooler operation is determined as follows:

$A = 24°$—Change in air temperature due to 800 kw.

$B = 38°$—Entering air temperature with 2° margin from 40° C.

$K = 62°$—A plus B.

$Q_1 = 25.5°$ (78° F.) Temperature of condensate at 29 in. Vacuum.

$T_1 - K - Q_1 = 42.5$.

From equation (1), the percentage of energy diverted to the condensate will be 88½ per cent, and from formula (2) the maximum cold water can reach a value as high as 36.5 degrees. Similarly, for 29½ in. of vacuum, when the condensate temperature will be approximately 88 deg. fahr. (31.3 deg. cent.) the percent heat diversion will be 64.5, and for 28 in. of vacuum, with a condensate temperature of 93 deg. fahr. (36.6 deg. cent.), the diversion will be 53 per cent. With the cold water cooler as proposed, the maximum possible temperature of $Q_2$ is always possible, as shown by equation (2).

Therefore, the values x and z, together with the proportions of the tubes in the cooler and the air and water velocity, will determine the physical size of the cooler. To illustrate with a certain size of tube and air velocity, the cold water element in the above example would require nine rows of tubes, while the condensate element would require an additional nine rows of tubes, consisting of three water passes of three rows of tubes in parallel per pass. The combined cooler would, therefore, consist of 18 rows of tubes in depth of the air flow.

As a comparison, the cooler using cold water only at 80 deg. fahr. for the water, and an entering temperature of the air to the generator of 38 deg. cent. would require a value of x equal to 0.68. For such a drop, the number of tubes, depthwise, would be 12. In other words, the cold water cooler designed to handle all the losses at summer temperature for cooling water would be two-thirds of the size of a combination cooler, using condensate, and, further, would have two-thirds of the air pressure drop. Design for the same pressure drop and the velocity of the air could be increased 23 per cent, so that the relative size for the same air drop is approximately 2 to 1. The air drop through the cooler is a direct function of the number of rows of tubes in depth times the square of the air velocity, between tubes. A considerable difference in the cost of coolers is apparent, if it is attempted to recover the heat in the condensate. This naturally raises the question as to whether the expense of the condensate cooler is justified. The answer depends on the cost of other methods of heating condensate.

In stations where two or more stage bleeding is used to heat the condensate, it requires a layout of the heat balance to determine whether the extra cost of condensate air cooler is warranted. The heat recover from the cooler reduces the amount of steam bled at the lowest pressure, and the value of this reduction in saving at the boiler is largely determined by the temperature of the lowest point of bleeding. If steam can be bled at four or five pounds absolute, it has a relatively high total B.t.u. content, but only a small percentage of this heat can be converted to power if passed through the turbine to the condenser. Therefore, the bleeding efficiency is high. There is, of course, some additional cost in bleeding, but this cost can be balanced against extra investment in the cooler. Under the conditions outlined, there would appear, ordinarily, to be very little in favor of the condensate cooler.

### Equipment Involved

For a surface cooler of the cold water type, the equipment involved consists of the cooler elements, the piping, the air duct, and, in some cases, a pump for circulating water. In other cases, the main circulating pump to the condenser may be able to pass the water to the cooler in parallel to the condenser. This water is then returned to the intake side of the pump or else thrown away. This possibility depends on the relative pumping head to the main condenser and the cooler.

For a combined cooler, using condensate, the same equipment as specified above for the cold water element is necessary, plus an additional allowance in head for the condensate pump to overcome the added friction of that cooler element which uses condensate. In both cases, a temperature indicating device, showing the temperature of the entering air to the generator, should be installed. In the combined cooler, the control of the cold water element in most cases would preferably be manually operated by the station attendant, as load conditions would be sufficiently steady, so that very little attention would be needed.

### Conclusions

The closed air system has certain undoubted advantages which have been enumerated. It is generally recognized that these advantages are worth while. The surface cooler in connection with the closed air system also has certain advantages in the way of compactness, cleanliness, freedom from moisture, etc. The unknown factors are cost and life of the equipment. Undoubtedly, the first can be secured from many manufacturers, and will be stabilized in time. The second is problematic, but at present can be compared to condenser life, as the service conditions are quite similar. Where salt water is the only available cooling medium, the surface cooler would seem to have everything in its favor. The use of condensate as a cooling medium cannot always be justified. As shown, the percentage of the heat recovered to the condensate depends, to a large extent, on the use of high vacuum. The cooler cost is bound to be higher than for a cooler not recovering heat, and the investment must be balanced against the operating cost involved in other methods of heating the condensate.

The surface coolers now manufactured for cooling the air circulating in a closed ventilating system in general consist of a series of finned tubes arranged so as to give the necessary area to prevent undue restriction in the flow of the air, the tubes being standard condenser tubes having applied to them copper fins. These fins give a large ratio of air cooling surface, approximately seven to one, so that the cooler can be assembled in a small space.

This further emphasizes one of the chief advantages of closed system of ventilation, namely, small volume of air content in the circulating system which gives a limited volume of oxygen to support combustion. The amount of dirt which enters the system is almost entirely eliminated in a closed system either with spray or ventilating cooling. The surface cooler has the further advantage of regaining the losses of the generator by using the condensate from the steam turbine for circulating through the regulators. The surface cooler can be installed in the small space generally directly beneath the generator which simplifies the ducts for the ventilating system. A practically constant temperature is obtained for the windings independent of load when the condensate is used as a cooling medium. The surface cooler has no water in direct contact with the air, thus removing the necessity of moisture eliminators and preventing rusting of the ducts.

There is now one of these coolers in successful operation at the Amsterdam steam plant of the Adirondack Power Company. This consists of a duct leading from the base of the machine through air coolers and so that the losses of the generator are regained as heat. By this means of ventilation dust is eliminated from the generator and the quantity of air is so limited that in case of fire, combustion would not be supported for any length of time. The room taken by the cooling system is less than that required by taking air from the outside and passing it through washers. In this particular case the cost of installing the ventilating system was about two-thirds of that which would be required to install a system of air washers. Inasmuch as the air is dry and clean, the possibility of the formation of a muddy film caused by dust and moist air, that is later baked on the windings, is eliminated. Less water is required for cooling than is taken by air washers, and less pumping losses are involved since the air washer required a considerable head of water to properly atomize it.

## DUCT DESIGN FOR MECHANICAL DRAFT

For air, as well as other fluids, smooth flow is desirable. Air ducts for forced and induced draft should therefore be designed to permit smooth flow and at low velocities as compared to steam velocities. The pressure put up by centrifugal fans for draft work is usually limited to 8 in. water pressure; less that 3/10 pounds per square inch. The resistance through the furnace may be 5 in. or 6 in.; consequently, not much pressure is left for duct friction.

There are numerous methods of designing a duct system and the final results will vary, as the various formulas and methods are based on constants of different values. One method is to assume a velocity. After designing the system the friction can be determined by using Weisbach's formula $P — f \frac{L\,v^2}{d\,2g}$. When this is converted into a form that gives the pressure loss in ounce per square inch, the length in feet, the diameter in inches and the velocity in feet per second, we get, using the value of f as 0.0001608, the form $p — \frac{Lv^2}{25000d}$. Many tables of the pressure-drop in air ducts have been developed from the foregoing formula. If the designer is not familiar with air duct practice he may choose a velocity that would be so high as to require a considerable pressure to produce the air flow needed; or, on the other hand, he might start with a velocity so low as to require a duct too large for the space available. It is therefore a matter of practice to design an air duct of economic proportions.

A second method would be to assume or determine the pressure loss that could be allowed between the wind box and the fan. Knowing the length of duct then from Weisbach's formula determine the value of $\frac{v^2}{d}$. With a given volume to start with we can substitute for the value of v volume divided by area. This then leaves only area and d unknown. But the area can be considered circular and expressed in a term of d. Then solving for d the diameter can be found.

Air has weight; consequently, moving air when arrested will develop a pressure head. It is usual to designate this as velocity pressure. From the law of falling bodies we derive the equation $v = 4000\sqrt{h}$ where "v" is velocity in feet per minute and "h" is head in inches of water. From the equation for pressure loss we can derive the loss in terms of velocity pressure and the length of pipe in terms of diameter. When the friction loss is equal to the velocity pressure the length will be found to be approximately 40 diameters. Consequently, it is customary to determine friction loss on the basis of velocity pressure and the duct length in terms of the duct diameter. Thus air flowing at 2000 per minute will represent a velocity pressure of ¼ in. water pressure as $v = 4000\sqrt{h}$ or $h = \frac{v^2}{(4000)^2}$ or $\frac{(2000)^2}{(4000)^2}$ or ¼. If the duct is 60 ft. long and 2 ft. in diam., 40 diam. would equal 80 ft., so that in 60 ft. it would represent a pressure loss equal $\frac{60}{80}$ or ¾ to the velocity pressure of ¾ of ¼ in.

The foregoing is on the basis of a fan discharging air through a duct system terminating in one outlet and in the system a uniform velocity being maintained. A different procedure is advisable where a duct system has numerous outlets. Starting from the fan outlet with a certain area duct, which fixes the velocity, we can reduce the area beyond the first outlet for a smaller volume is now flowing. If we reduce the area so that the same velocity results we do not have the same friction effect, for the ratio of perimeter to cross sectional area is a factor in friction and a system so designed would be difficult to balance to produce the correct discharge through the different outlets. It is customary to reduce the velocity in duct as the area is reduced, to maintain the friction effect uniform.

A much better method is to proportion piping systems on a basis of equivalent areas. For a fair degree of accuracy and ease of handling, tables of equivalent areas are based on 5 in. diam. pipes. The table of sizes used is based on the carrying capacity of pipes. At the same velocity of flow, the volume delivered by two pipes of different sizes is proportional to the squares of their diameters. With the same head, however, the velocity is less in a smaller pipe and the volume varies about as the square root of the fifth power. Let us assume a system is to be designed to deliver air through 16 outlets and each outlet to deliver 1500 feet of air per minute. Let us assume an initial velocity of 2400 ft. per minute at the fan outlet. Sixteen outlets each delivering 1500 cu. ft. per minute require a total of 24,000 cu. ft. to be delivered by the fan. With a velocity of 2400 ft. per minute the area of duct at the fan outlet should be $\frac{24000}{2400}$ or 10 sq. ft. which is equivalent to 1440 sq. in. This is approximately the area of 43 in. pipe. Referring to a table of 5's we find a 43 in. pipe is equivalent to 215 5-in. pipes. Having

24,000 cu. ft. flowing and 215 5-in. pipes the volume per 5-in. pipe is $\frac{24000}{215}$ or 111.5 cu. ft. Having 1500 from each outlet we require $\frac{1500}{111.5}$ or 13.5 5-in. pipes, which is approximately equivalent to a 14-in. pipe, the size of each outlet. Consequently, each of the 16 branches will be 14 in. in diam. The pipe size to supply two outlets will be equivalent to 2 x 13.5 or 27 5-in. pipes. The equivalent of which would be a 19-in. pipe; for 3 outlets 40 5-in pipes or a 22-in. pipe; for four outlets 54 5-in. or a 25-in. pipe, etc., until for the 16 outlets we have 215 5-in. pipes or a 43-in. pipe. Now, to determine the friction we can consider the pipe of a uniform diam. of 43-in. and a uniform velocity of 2400 feet per min. Then using the formula $p = \frac{Lv^2}{25000d}$ we can determine the pressure drop through the system, or use the method of the length in diameters and the velocity pressure lost in each 40 diameters.

The discharge of equivalent pipe sizes and the friction in inches of water per 100 ft. of length for round and rectangular pipes has been developed into many tables and charts. The tables used by the B. F. Sturtevant Company are published herewith. (Tables III to IX inclusive.)

It is evident that the higher the velocity the greater the friction and the greater the pressure must be put by the fan to overcome the friction or resistance. It is also evident that pressure is a measure of work and the rate of work is the power. Therefore, there is economy in low velocity systems. However, there is a point below which the saving in power due to the low velocity is offset by investment and depreciation charges on the duct system, and by the charges on the space occupied by the duct if it is usable space. The point below which a further reduction in velocity does not produce saving in power to offset investment charges is termed by some the optimum velocity. It will generally be found for systems in which the pressure is 1 in. that the static pressure should be 80 per cent of the total pressure; or the velocity pressure should be about 25 per cent of the static pressure. When the pressure is 6 in. the economical condition is found where the static pressure is 90 per cent of the total pressure or the velocity pressure about 11 per cent of the static pressure.

Any change in velocity, or direction of flow of fluids is accompanied by a loss in energy. To abruptly stop the flow of air is to lose the pressure equivalent to the velocity pressure. To change the direction flow at sharp right angles results in the velocity pressure loss. Sharp edges, projections and irregularities cause eddy currents and unnecessary loss in velocity and unnecessary increase in friction. Consequently, duct work should be made with smooth joints of uniform cross section and with large radius turns. Branch connections to ducts should be tapered and taken off at an angle not greater than 45 degrees. Any change in area should be made by means of a transformation piece with a slope of about 10 degrees.

Duct leakage has been the cause of the failure of a boiler to meet its guaranteed rating. Leakage into and from draft ducts should be eliminated. Where concrete is used for duct work unusual care must be used to prevent leakage. All concrete air ducts for pressures of several inches should be coated inside with neat cement and painted inside under pressure with oil paint. Average concrete will have a friction coefficient twice that of sheet steel, hence care must be had to produce smooth surfaces.

Duct resistance varies as the square of the velocity. Volume discharged varies the square root of the head. A duct system is the orifice of a fan and for the same orifice the fan performance will vary with the speed.

The volume will vary directly with the speed. As velocity is a function of volume and as head or pressure varies as the square of the velocity, then the resistance varies as the square of the speed. Power varies as the cube of the speed. Consequently, a slight increase in speed results in a considerable increase in power. If then a fan motor which has been applied with very little excess capacity runs 7 per cent high the load will be more than 20 per cent high and will result in an overheaded motor. On the other hand, a slightly overloaded fan motor can be corrected by a slight reduction in speed and usually the slight decrease in air delivery would not be noticed.

Both straight blade and forward curved blade fans have large volumetric capacity. If such fans are applied for operation against considerable resistance and operated at the proper speed for the estimated resistance the air delivery will be, if the resistance should happen to be less than estimated, much greater than required with a consequent increase in power. Hence as it is difficult to determine the resistance of a system absolutely some excess motor capacity should be provided for this condition. The fully backward curved blade fan such as the Sturtevant Silentvane and design 5 Turbovane have a self limiting horse-power characteristic and with such fans the power required with decreased resistance will under many conditions be less than that for the estimated conditions. If the fan was properly chosen for the estimated conditions the power cannot be higher than that for the estimated conditions irrespective of the pressure at the estimated speed.

### Use of Tables of Air Ducts

The tables of air ducts equalized for constant frictions are based on equivalent areas for constant friction. In using the tables the designer, having first determined the total volume of air to be handled, decides upon the friction drop per hundred feet of pipe he desires the system to have. The tables are based on frictions (inches water gauge) per hundred feet of pipe varying from 0.04 in. to 0.4 in. It is only from experience and with a knowledge of various air systems that the

(Continued on page 38)

## TABLE III

### Air Ducts Equalized for Constant Friction (B. F. Sturtevant Co.)

| FRICTION PER 100 FOOT PIPE IN INCHES OF WATER | | | | | | | | | | | | | Dia. in Ins. | CORRESPONDING RECTANGULAR DUCT | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .40 | .35 | .30 | .25 | .20 | .18 | .16 | .14 | .12 | .10 | .08 | .06 | .04 | | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| Cubic Feet of Air per Minute | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 81 | 76 | 71 | 64 | 58 | 55 | 51 | 48 | 45 | .. | .. | .. | .. | 4.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 110 | 100 | 94 | 86 | 77 | 73 | 69 | 64 | 60 | 55 | 49 | .. | .. | 4.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 140 | 130 | 120 | 110 | 100 | 95 | 90 | 83 | 78 | 71 | 63 | 55 | 45 | 5.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 180 | 170 | 150 | 140 | 130 | 120 | 110 | 100 | 97 | 89 | 80 | 69 | 56 | 5.5 | 6 | 5 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 220 | 210 | 190 | 180 | 160 | 150 | 140 | 130 | 120 | 110 | 100 | 87 | 70 | 6.0 | 8 | 6 | 5 | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 270 | 260 | 240 | 220 | 190 | 180 | 170 | 160 | 150 | 140 | 120 | 110 | 86 | 6.5 | 9 | 7 | 6 | 5 | .. | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 330 | 310 | 280 | 260 | 230 | 220 | 210 | 190 | 180 | 160 | 150 | 130 | 110 | 7.0 | 11 | 8 | 7 | 6 | 5 | .. | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 390 | 370 | 340 | 310 | 280 | 260 | 250 | 230 | 210 | 200 | 180 | 150 | 120 | 7.5 | 13 | 10 | 8 | 7 | 6 | 5 | 5 | .. | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 460 | 430 | 400 | 360 | 320 | 310 | 290 | 270 | 250 | 230 | 210 | 180 | 150 | 8.0 | 14 | 11 | 9 | 8 | 7 | 6 | .. | 5 | .. | .. | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 530 | 500 | 460 | 420 | 380 | 360 | 340 | 320 | 290 | 270 | 240 | 210 | 170 | 8.5 | 17 | 13 | 10 | 9 | .. | 7 | 6 | .. | 5 | 5 | .. | .. | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 620 | 580 | 530 | 490 | 440 | 410 | 390 | 370 | 340 | 310 | 280 | 240 | 200 | 9.0 | 19 | 14 | 12 | 10 | 8 | .. | 7 | 6 | 6 | .. | 5 | 5 | .. | .. | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 710 | 660 | 610 | 560 | 500 | 470 | 450 | 420 | 390 | 350 | 320 | 270 | 220 | 9.5 | 21 | 16 | 13 | 11 | 9 | 8 | .. | 7 | .. | 6 | .. | .. | 5 | .. | .. | .. | 4 | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 800 | 750 | 690 | 630 | 570 | 540 | 510 | 470 | 440 | 400 | 360 | 310 | 250 | 10.0 | 24 | 18 | 14 | 12 | 11 | 9 | 8 | 8 | 7 | .. | 6 | 6 | .. | 5 | 5 | .. | .. | .. | .. | 4 | 4 | 4 | .. | .. | .. | .. | .. | .. |
| 910 | 850 | 780 | 720 | 640 | 610 | 570 | 540 | 500 | 450 | 400 | 350 | 290 | 10.5 | 27 | 20 | 16 | 13 | 12 | 10 | 9 | .. | 8 | 7 | .. | .. | 6 | .. | .. | 5 | 5 | .. | .. | .. | .. | .. | 4 | 4 | .. | .. | .. | .. |
| 1020 | 960 | 890 | 810 | 720 | 690 | 650 | 610 | 560 | 510 | 460 | 400 | 320 | 11.0 | 30 | 22 | 18 | 15 | 13 | 11 | 10 | 9 | .. | 8 | 7 | 7 | .. | 6 | 6 | .. | .. | 5 | 5 | 5 | .. | .. | .. | .. | 4 | 4 | 4 | 4 |
| 1130 | 1060 | 980 | 900 | 800 | 760 | 720 | 670 | 620 | 570 | 510 | 440 | 360 | 11.5 | 33 | 25 | 19 | 16 | 14 | 12 | 11 | 10 | 9 | .. | 8 | .. | 7 | .. | .. | 6 | 6 | .. | .. | .. | 5 | 5 | .. | .. | .. | .. | .. | .. |
| 1260 | 1180 | 1100 | 1000 | 890 | 850 | 800 | 750 | 690 | 630 | 570 | 490 | 400 | 12.0 | 37 | 27 | 21 | 18 | 15 | 13 | 12 | 11 | 10 | 9 | .. | 8 | .. | 7 | 7 | .. | .. | 6 | 6 | .. | .. | .. | 5 | 5 | 5 | .. | .. | .. |
| 1400 | 1310 | 1210 | 1100 | 990 | 940 | 890 | 830 | 770 | 700 | 630 | 540 | 440 | 12.5 | 40 | 30 | 24 | 20 | 17 | 15 | 13 | 12 | 11 | 10 | 9 | 9 | 8 | 8 | .. | 7 | 7 | .. | .. | 6 | 6 | .. | .. | .. | .. | 5 | 5 | 5 |
| 1540 | 1440 | 1340 | 1220 | 1090 | 1040 | 980 | 910 | 850 | 770 | 690 | 600 | 490 | 13.0 | 44 | 33 | 26 | 21 | 18 | 16 | 14 | 13 | 12 | 11 | 10 | .. | 9 | .. | 8 | .. | .. | 7 | .. | .. | .. | 6 | 6 | .. | .. | .. | .. | .. |
| 1700 | 1590 | 1470 | 1340 | 1200 | 1140 | 1070 | 1000 | 930 | 850 | 760 | 660 | 540 | 13.5 | 48 | 36 | 28 | 23 | 20 | 17 | 15 | 14 | 13 | 12 | 11 | 10 | .. | 9 | .. | 8 | 8 | .. | 7 | 7 | .. | .. | .. | 6 | 6 | 6 | .. | .. |
| 1860 | 1740 | 1610 | 1470 | 1310 | 1250 | 1180 | 1100 | 1020 | 930 | 830 | 720 | 590 | 14.0 | .. | 39 | 31 | 25 | 21 | 19 | 17 | 15 | .. | .. | .. | 11 | 10 | 10 | 9 | 9 | .. | 8 | .. | .. | 7 | 7 | .. | .. | .. | .. | 6 | 6 |
| 2040 | 1900 | 1760 | 1610 | 1440 | 1370 | 1290 | 1200 | 1110 | 1020 | 910 | 790 | 640 | 14.5 | .. | 42 | 33 | 27 | 23 | 20 | 18 | 16 | 15 | 13 | 12 | 12 | 11 | .. | 10 | .. | 9 | .. | 8 | 8 | .. | .. | 7 | 7 | .. | .. | .. | .. |
| 2210 | 2070 | 1920 | 1750 | 1560 | 1480 | 1400 | 1310 | 1210 | 1110 | 990 | 860 | 700 | 15.0 | .. | 46 | 36 | 29 | 25 | 21 | 19 | 17 | 16 | 14 | 13 | .. | 12 | 11 | .. | 10 | .. | 9 | 9 | .. | 8 | 8 | .. | .. | 7 | 7 | 7 | .. |
| 2400 | 2240 | 2080 | 1900 | 1700 | 1610 | 1520 | 1420 | 1310 | 1200 | 1070 | 930 | 760 | 15.5 | .. | 49 | 39 | 32 | 27 | 23 | 20 | 18 | 17 | 15 | 14 | 13 | .. | 12 | 11 | .. | 10 | 10 | .. | 9 | .. | .. | 8 | 8 | .. | .. | .. | 7 |
| 2600 | 2430 | 2250 | 2060 | 1840 | 1750 | 1650 | 1540 | 1430 | 1300 | 1160 | 1010 | 820 | 16.0 | .. | .. | 42 | 34 | 29 | 25 | 22 | 20 | 18 | 16 | 15 | 14 | 13 | .. | 12 | 11 | 11 | .. | 10 | .. | 9 | 9 | .. | .. | 8 | 8 | .. | .. |
| 2800 | 2620 | 2420 | 2210 | 1980 | 1880 | 1770 | 1660 | 1530 | 1400 | 1250 | 1080 | 880 | 16.5 | .. | .. | 45 | 36 | 31 | 26 | 23 | 21 | 19 | 17 | 16 | 15 | 14 | 13 | .. | 12 | .. | 11 | .. | 10 | .. | .. | 9 | 9 | .. | .. | 8 | 8 |
| 3020 | 2830 | 2620 | 2390 | 2140 | 2030 | 1910 | 1790 | 1650 | 1510 | 1350 | 1170 | 960 | 17.0 | .. | .. | 48 | 39 | 33 | 28 | 25 | 22 | 20 | 19 | 17 | 16 | 15 | 14 | 13 | 13 | 12 | .. | 11 | .. | 10 | 10 | .. | .. | 9 | 9 | .. | .. |
| 3240 | 3030 | 2810 | 2560 | 2290 | 2180 | 2050 | 1920 | 1780 | 1620 | 1450 | 1260 | 1030 | 17.5 | .. | .. | .. | 42 | 35 | 30 | 27 | 24 | 21 | 20 | 18 | 17 | 16 | 15 | 14 | .. | 13 | 12 | 12 | 11 | 11 | .. | 10 | 10 | .. | .. | 9 | 9 |
| 3490 | 3260 | 3020 | 2760 | 2460 | 2340 | 2200 | 2060 | 1910 | 1740 | 1560 | 1350 | 1100 | 18.0 | .. | .. | .. | 44 | 37 | 32 | 28 | 25 | 23 | 21 | 19 | 18 | 17 | 16 | 15 | 14 | .. | 13 | .. | 12 | .. | 11 | .. | .. | 10 | .. | .. | .. |
| 3730 | 3490 | 3230 | 2950 | 2640 | 2500 | 2360 | 2210 | 2040 | 1860 | 1670 | 1440 | 1180 | 18.5 | .. | .. | .. | 47 | 40 | 34 | 30 | 27 | 24 | 22 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | .. | 13 | .. | 12 | .. | 11 | 11 | .. | 10 | 10 | .. |
| 3990 | 3730 | 3450 | 3150 | 2820 | 2670 | 2520 | 2360 | 2180 | 2000 | 1780 | 1540 | 1260 | 19.0 | .. | .. | .. | .. | 42 | 36 | 32 | 28 | 26 | 23 | 22 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 14 | 13 | .. | 12 | 12 | .. | 11 | 11 | .. | 10 |
| 4260 | 3980 | 3690 | 3370 | 3010 | 2860 | 2690 | 2520 | 2330 | 2130 | 1900 | 1650 | 1350 | 19.5 | .. | .. | .. | .. | 45 | 39 | 34 | 30 | 27 | 25 | 23 | 21 | 20 | .. | .. | .. | 16 | 15 | .. | 14 | 13 | 13 | .. | 12 | .. | .. | 11 | .. |
| 4540 | 4240 | 3930 | 3590 | 3210 | 3040 | 2870 | 2680 | 2480 | 2270 | 2030 | 1760 | 1430 | 20.0 | .. | .. | .. | .. | 48 | 41 | 36 | 32 | 29 | 26 | 24 | 22 | 21 | 20 | 18 | 17 | 17 | 16 | 15 | .. | 14 | .. | 13 | .. | 12 | 12 | .. | 11 |
| 4820 | 4510 | 4180 | 3810 | 3410 | 3240 | 3050 | 2850 | 2640 | 2410 | 2160 | 1870 | 1530 | 20.5 | .. | .. | .. | .. | .. | 43 | 38 | 33 | 30 | 27 | 25 | 23 | 22 | .. | 19 | 18 | .. | .. | 16 | 15 | .. | 14 | .. | 13 | 13 | .. | 12 | .. |
| 5120 | 4790 | 4440 | 4050 | 3620 | 3440 | 3240 | 3030 | 2810 | 2560 | 2290 | 1980 | 1620 | 21.0 | .. | .. | .. | .. | .. | 46 | 40 | 35 | 32 | 29 | 27 | 25 | 23 | 22 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 14 | .. | 13 | .. | 12 |
| 5430 | 5080 | 4700 | 4290 | 3840 | 3640 | 3430 | 3210 | 2970 | 2710 | 2430 | 2100 | 1720 | 21.5 | .. | .. | .. | .. | .. | 48 | 42 | 37 | 34 | 30 | 28 | 26 | 24 | .. | 21 | 20 | 19 | 18 | .. | .. | 16 | .. | 15 | .. | 14 | .. | 13 | 13 |
| 5760 | 5390 | 4990 | 4560 | 4080 | 3870 | 3640 | 3410 | 3160 | 2880 | 2580 | 2230 | 1820 | 22.0 | .. | .. | .. | .. | .. | 51 | 44 | 39 | 35 | 32 | 29 | 27 | 25 | 24 | 22 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | .. | 15 | .. | 14 | 14 | .. |
| 6090 | 5700 | 5270 | 4810 | 4310 | 4080 | 3850 | 3600 | 3330 | 3040 | 2720 | 2360 | 1930 | 22.5 | .. | .. | .. | .. | .. | 54 | 47 | 41 | 37 | 34 | 31 | 28 | 26 | 25 | 23 | 22 | 21 | 20 | 19 | 18 | .. | 17 | 16 | .. | 15 | 15 | .. | 14 |
| 6450 | 6030 | 5590 | 5100 | 4560 | 4330 | 4080 | 3820 | 3520 | 3230 | 2880 | 2500 | 2040 | 23.0 | .. | .. | .. | .. | .. | .. | 49 | 44 | 39 | 35 | 32 | 30 | 28 | 26 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | .. | 17 | 16 | 16 | .. | 15 | .. |
| 6790 | 6350 | 5880 | 5360 | 4800 | 4550 | 4290 | 4020 | 3720 | 3390 | 3030 | 2630 | 2150 | 23.5 | .. | .. | .. | .. | .. | .. | 52 | 46 | 41 | 37 | 34 | 31 | 29 | 27 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | .. | 17 | .. | 16 | .. | 15 |
| 7150 | 6690 | 6190 | 5650 | 5060 | 4800 | 4520 | 4230 | 3920 | 3570 | 3200 | 2770 | 2260 | 24.0 | .. | .. | .. | .. | .. | .. | 54 | 48 | 43 | 39 | 35 | 33 | 30 | 28 | 27 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | .. | 16 | .. |
| 7540 | 7050 | 6530 | 5960 | 5330 | 5060 | 4770 | 4460 | 4130 | 3770 | 3370 | 2920 | 2380 | 24.5 | .. | .. | .. | .. | .. | .. | 57 | 50 | 45 | 41 | 37 | 34 | 32 | 30 | 28 | 26 | 25 | 24 | .. | .. | 21 | 20 | 19 | .. | 18 | 17 | 17 | 16 |
| 7950 | 7430 | 6880 | 6280 | 5620 | 5330 | 5020 | 4700 | 4350 | 3970 | 3550 | 3080 | 2510 | 25.0 | .. | .. | .. | .. | .. | .. | 60 | 52 | 47 | 42 | 39 | 36 | 33 | 31 | 29 | 27 | 26 | 25 | 23 | 22 | .. | 21 | 20 | 19 | .. | 18 | .. | 17 |
| 8320 | 7780 | 7200 | 6580 | 5880 | 5580 | 5260 | 4920 | 4560 | 4160 | 3720 | 3220 | 2630 | 25.5 | .. | .. | .. | .. | .. | .. | .. | 55 | 49 | 44 | 40 | 37 | 35 | 32 | 30 | 28 | 27 | 26 | 24 | 23 | 22 | .. | 21 | .. | 19 | .. | 18 | .. |
| 8750 | 8180 | 7580 | 6910 | 6180 | 5870 | 5530 | 5170 | 4790 | 4370 | 3910 | 3390 | 2770 | 26.0 | .. | .. | .. | .. | .. | .. | .. | 57 | 51 | 46 | 42 | 39 | 36 | 34 | 32 | 30 | 28 | .. | 25 | 24 | 23 | 22 | .. | .. | 20 | 19 | 19 | 18 |
| 9160 | 8570 | 7940 | 7250 | 6480 | 6150 | 5800 | 5420 | 5020 | 4580 | 4100 | 3550 | 2900 | 26.5 | .. | .. | .. | .. | .. | .. | .. | 60 | 54 | 48 | 44 | 41 | 37 | 35 | 33 | 31 | 29 | 28 | 26 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | .. | 19 |
| 9620 | 9000 | 8330 | 7600 | 6800 | 6450 | 6080 | 5690 | 5270 | 4810 | 4300 | 3730 | 3040 | 27.0 | .. | .. | .. | .. | .. | .. | .. | 62 | 56 | 50 | 46 | 42 | 39 | 37 | 34 | 32 | 30 | 29 | 27 | 26 | 25 | 24 | 23 | 22 | .. | 21 | 20 | .. |
| 10000 | 9400 | 8700 | 7940 | 7110 | 6740 | 6360 | 5950 | 5500 | 5020 | 4490 | 3890 | 3180 | 27.5 | .. | .. | .. | .. | .. | .. | .. | .. | 58 | 53 | 48 | 44 | 41 | 38 | 36 | 33 | 32 | 30 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | .. | 21 | 20 |
| 10500 | 9860 | 9130 | 8330 | 7450 | 7070 | 6670 | 6240 | 5770 | 5270 | 4710 | 4080 | 3330 | 28.0 | .. | .. | .. | .. | .. | .. | .. | .. | 61 | 55 | 50 | 46 | 42 | 39 | 37 | 35 | 33 | 31 | 30 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 22 | 21 |
| 11000 | 10300 | 9520 | 8690 | 7780 | 7380 | 6950 | 6510 | 6020 | 5500 | 4920 | 4260 | 3480 | 28.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 57 | 52 | 48 | 44 | 41 | 38 | 36 | 34 | 32 | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | .. | 22 |
| 11500 | 10700 | 9940 | 9070 | 8120 | 7700 | 7260 | 6790 | 6290 | 5740 | 5130 | 4450 | 3630 | 29.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 59 | 54 | 50 | 46 | 43 | 40 | 37 | 35 | 34 | 32 | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 23 |
| 12000 | 11200 | 10400 | 9470 | 8470 | 8040 | 7580 | 7090 | 6560 | 5990 | 5360 | 4640 | 3790 | 29.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 62 | 56 | 52 | 48 | 44 | 41 | 39 | 37 | 35 | 33 | .. | 30 | 29 | 28 | 27 | 26 | 25 | 24 | .. |
| 12500 | 11700 | 10800 | 9880 | 8840 | 8390 | 7910 | 7400 | 6850 | 6250 | 5590 | 4840 | 3950 | 30.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 64 | 58 | 54 | 49 | 46 | 43 | 40 | 38 | 36 | 34 | 33 | 31 | 30 | 29 | .. | .. | 26 | 25 | 24 |
| 13000 | 12200 | 11300 | 10300 | 9200 | 8730 | 8230 | 7700 | 7130 | 6510 | 5820 | 5040 | 4120 | 30.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 60 | 56 | 51 | 47 | 45 | 42 | 39 | 37 | 35 | 34 | 32 | 31 | .. | 28 | 27 | .. | .. | 25 |

NOTE:—Tables figured for C. I. pipes: for concrete ducts, friction is 50% more.

## TABLE IV

### AIR DUCTS EQUALIZED FOR CONSTANT FRICTION (B. F. STURTEVANT CO.)

| Dia. In Inches | CORRESPONDING RECTANGULAR DUCT | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 |
| 11.5 | 4 | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 12.0 | .. | .. | .. | 4 | 4 | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 12.5 | .. | .. | .. | .. | .. | .. | .. | 4 | 4 | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 13.0 | 5 | 5 | 5 | .. | .. | .. | .. | .. | .. | .. | .. | 4 | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 13.5 | .. | .. | .. | 5 | 5 | 5 | .. | .. | .. | .. | .. | .. | .. | .. | 4 | 4 | 4 | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 14.0 | .. | .. | .. | .. | .. | .. | 5 | 5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 14.5 | 6 | 6 | 6 | .. | .. | .. | .. | .. | 5 | 5 | 5 | 5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 15.0 | .. | .. | .. | 6 | 6 | .. | .. | .. | .. | .. | .. | .. | 5 | 5 | 5 | 5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 15.5 | 7 | .. | .. | .. | .. | 6 | 6 | 6 | 6 | .. | .. | .. | .. | .. | .. | .. | 5 | 5 | 5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 16.0 | .. | 7 | 7 | .. | .. | .. | .. | .. | .. | 6 | 6 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 16.5 | .. | .. | .. | 7 | 7 | 7 | .. | .. | .. | .. | .. | 6 | 6 | 6 | 6 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 17.0 | 8 | 8 | .. | .. | .. | .. | 7 | 7 | 7 | .. | .. | .. | .. | .. | .. | 6 | 6 | 6 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 17.5 | .. | .. | 8 | 8 | 8 | .. | .. | .. | .. | 7 | 7 | .. | .. | .. | .. | .. | .. | .. | 6 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 18.0 | 9 | 9 | .. | .. | .. | 8 | 8 | .. | .. | .. | .. | 7 | 7 | 7 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 18.5 | .. | .. | 9 | 9 | .. | .. | .. | 8 | 8 | .. | .. | .. | .. | .. | 7 | 7 | 7 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 19.0 | 10 | .. | .. | .. | 9 | 9 | .. | .. | .. | 8 | 8 | 8 | .. | .. | .. | .. | .. | 7 | 7 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 19.5 | .. | 10 | 10 | .. | .. | .. | 9 | 9 | .. | .. | .. | .. | 8 | 8 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 20.0 | 11 | .. | .. | 10 | 10 | .. | .. | .. | 9 | 9 | .. | .. | .. | .. | 8 | 8 | 8 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 20.5 | .. | 11 | 11 | .. | .. | 10 | 10 | .. | .. | .. | 9 | 9 | 9 | .. | .. | .. | .. | 8 | 8 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 21.0 | 12 | .. | .. | 11 | 11 | .. | .. | 10 | 10 | .. | .. | .. | .. | 9 | 9 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 21.5 | .. | 12 | 12 | .. | .. | 11 | 11 | .. | .. | 10 | 10 | .. | .. | .. | .. | 9 | 9 | 9 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 22.0 | 13 | .. | .. | 12 | 12 | .. | .. | 11 | 11 | .. | .. | 10 | 10 | 10 | .. | .. | .. | .. | 9 | 9 | 9 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 22.5 | .. | 13 | 13 | .. | .. | 12 | .. | .. | .. | 11 | 11 | .. | .. | .. | 10 | 10 | .. | .. | .. | .. | .. | 9 | 9 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 23.0 | 14 | 14 | .. | 13 | 13 | .. | 12 | 12 | .. | .. | .. | 11 | 11 | .. | .. | .. | 10 | 10 | 10 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 23.5 | .. | .. | 14 | .. | .. | 13 | .. | .. | 12 | 12 | .. | .. | .. | 11 | 11 | .. | .. | .. | .. | 10 | 10 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 24.0 | 15 | 15 | .. | 14 | 14 | .. | 13 | 13 | .. | .. | 12 | 12 | .. | .. | .. | 11 | 11 | .. | .. | .. | .. | 10 | 10 | 10 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 24.5 | 16 | .. | 15 | .. | .. | 14 | .. | .. | 13 | 13 | .. | .. | 12 | 12 | .. | .. | .. | 11 | 11 | 11 | .. | .. | .. | .. | 10 | 10 | 10 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 25.0 | .. | 16 | .. | 15 | 15 | .. | 14 | 14 | .. | .. | 13 | 13 | .. | .. | 12 | 12 | 12 | .. | .. | .. | 11 | 11 | .. | .. | .. | .. | .. | 10 | 10 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 25.5 | 17 | .. | 16 | 16 | .. | 15 | .. | .. | 14 | 14 | .. | .. | 13 | 13 | .. | .. | .. | 12 | 12 | .. | .. | .. | 11 | 11 | 11 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 26.0 | 18 | 17 | 17 | .. | 16 | .. | 15 | 15 | .. | .. | 14 | 14 | .. | .. | 13 | 13 | .. | .. | .. | 12 | 12 | .. | .. | .. | .. | 11 | 11 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 26.5 | .. | 18 | .. | 17 | .. | 16 | 16 | .. | 15 | 15 | .. | .. | 14 | .. | .. | .. | 13 | 13 | .. | .. | .. | 12 | 12 | .. | .. | .. | .. | 11 | 11 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 27.0 | 19 | .. | 18 | .. | 17 | 17 | .. | 16 | .. | .. | 15 | 15 | .. | 14 | 14 | .. | .. | .. | 13 | .. | .. | .. | .. | 12 | 12 | 12 | .. | .. | .. | 11 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 27.5 | 20 | 19 | 19 | 18 | 18 | .. | 17 | .. | 16 | 16 | .. | .. | 15 | .. | .. | 14 | 14 | .. | .. | 13 | 13 | 13 | .. | .. | .. | .. | 12 | 12 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 28.0 | .. | 20 | .. | 19 | .. | 18 | .. | 17 | 17 | .. | 16 | 16 | .. | 15 | 15 | .. | .. | 14 | 14 | .. | .. | .. | 13 | 13 | .. | .. | .. | .. | 12 | 12 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 28.5 | 21 | .. | 20 | .. | 19 | .. | 18 | .. | .. | 17 | .. | .. | 16 | .. | .. | 15 | 15 | .. | .. | 14 | 14 | .. | .. | .. | 13 | 13 | 13 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 29.0 | 22 | 21 | 21 | 20 | .. | 19 | 19 | 18 | 18 | .. | 17 | 17 | .. | 16 | 16 | .. | .. | 15 | 15 | .. | .. | 14 | 14 | .. | .. | .. | .. | 13 | 13 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 29.5 | .. | 22 | .. | 21 | 20 | 20 | .. | 19 | .. | 18 | .. | .. | 17 | .. | .. | 16 | 16 | .. | .. | 15 | 15 | .. | .. | 14 | 14 | .. | .. | .. | .. | 13 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 30.0 | 23 | 23 | 22 | .. | 21 | .. | 20 | .. | 19 | .. | 18 | 18 | .. | 17 | 17 | .. | .. | 16 | 16 | .. | .. | 15 | 15 | .. | .. | 14 | 14 | .. | .. | .. | 13 | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 30.5 | 24 | .. | 23 | 22 | .. | 21 | .. | 20 | .. | 19 | 19 | .. | 18 | 18 | .. | 17 | 17 | .. | .. | 16 | 16 | .. | .. | 15 | 15 | .. | .. | 14 | 14 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 31.0 | 25 | 24 | .. | 23 | 22 | 22 | 21 | 21 | 20 | 20 | .. | 19 | 19 | .. | 18 | .. | .. | 17 | 17 | .. | .. | 16 | 16 | .. | .. | 15 | 15 | .. | .. | 14 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 31.5 | .. | 25 | 24 | .. | 23 | .. | 22 | .. | 21 | .. | 20 | .. | .. | 19 | .. | 18 | 18 | .. | .. | 17 | .. | .. | .. | 16 | 16 | .. | .. | 15 | 15 | .. | 14 | 14 | .. | .. | .. | .. | .. | .. | .. | .. |
| 32.0 | 26 | 26 | 25 | 24 | 24 | 23 | .. | 22 | .. | 21 | 21 | 20 | 20 | .. | 19 | .. | .. | 18 | 18 | .. | 17 | 17 | .. | .. | .. | 16 | 16 | .. | .. | 15 | .. | .. | 14 | .. | .. | .. | .. | .. | .. | .. |
| 32.5 | 27 | .. | 26 | 25 | .. | 24 | 23 | .. | 22 | .. | .. | 21 | .. | 20 | .. | 19 | 19 | .. | .. | 18 | .. | .. | 17 | 17 | .. | .. | .. | 16 | 16 | .. | 15 | .. | .. | 14 | .. | .. | .. | .. | .. | .. |
| 33.0 | 28 | 27 | .. | 26 | 25 | .. | 24 | 23 | 23 | 22 | 22 | .. | 21 | .. | 20 | 20 | .. | 19 | 19 | .. | 18 | 18 | .. | .. | 17 | 17 | .. | .. | .. | 16 | .. | 15 | .. | .. | .. | .. | .. | .. | .. | .. |
| 33.5 | 29 | 28 | 27 | .. | 26 | 25 | .. | 24 | .. | 23 | .. | 22 | 22 | 21 | .. | .. | 20 | .. | .. | 19 | .. | .. | 18 | 18 | .. | .. | 17 | 17 | .. | .. | 16 | .. | 15 | .. | .. | .. | .. | .. | .. | .. |
| 34.0 | 30 | 29 | 28 | 27 | 27 | 26 | 25 | 25 | 24 | .. | 23 | .. | .. | 22 | 21 | 21 | .. | 20 | 20 | .. | 19 | 19 | .. | .. | 18 | 18 | .. | .. | 17 | .. | .. | 16 | .. | 15 | 15 | .. | .. | .. | .. | .. |
| 34.5 | 31 | 30 | 29 | 28 | .. | .. | 26 | .. | 25 | 24 | 24 | 23 | 23 | .. | 22 | .. | 21 | 21 | .. | 20 | 20 | .. | 19 | 19 | .. | .. | 18 | 18 | .. | 17 | .. | .. | 16 | .. | .. | 15 | .. | .. | .. | .. |
| 35.0 | 32 | 31 | 30 | 29 | 28 | 27 | 27 | 26 | .. | 25 | 25 | 24 | .. | 23 | .. | 22 | 22 | .. | 21 | .. | .. | 20 | .. | .. | 19 | 19 | .. | .. | 18 | .. | 17 | .. | .. | 16 | .. | .. | .. | .. | .. | .. |
| 35.5 | .. | .. | .. | 30 | 29 | 28 | .. | 27 | 26 | .. | .. | .. | 24 | .. | 23 | .. | .. | 22 | .. | 21 | 21 | .. | 20 | 20 | .. | .. | 19 | .. | .. | 18 | .. | 17 | .. | .. | 16 | .. | .. | .. | .. | .. |
| 36.0 | 33 | 32 | 31 | .. | 30 | 29 | 28 | .. | 27 | 26 | 26 | 25 | 25 | 24 | 24 | 23 | 23 | .. | 22 | .. | .. | 21 | .. | .. | 20 | 20 | .. | 19 | 19 | .. | 18 | .. | 17 | .. | .. | 16 | .. | .. | .. | .. |
| 36.5 | 34 | 33 | 32 | 31 | .. | 30 | 29 | 28 | 28 | 27 | .. | 26 | .. | 25 | .. | 24 | .. | 23 | .. | 22 | 22 | .. | 21 | 21 | .. | .. | 20 | .. | .. | 19 | .. | 18 | .. | 17 | 17 | .. | 16 | .. | .. | .. |
| 37.0 | 35 | 34 | 33 | 32 | 31 | 31 | 30 | 29 | .. | 28 | 27 | .. | 26 | .. | 25 | .. | 24 | .. | 23 | 23 | .. | 22 | 22 | .. | 21 | 21 | .. | 20 | 20 | .. | 19 | .. | 18 | .. | .. | 17 | .. | 16 | 16 | .. |
| 37.5 | 36 | 35 | 34 | 33 | 32 | .. | .. | 30 | 29 | .. | 28 | 27 | 27 | 26 | .. | 25 | .. | 24 | 24 | .. | 23 | 23 | .. | 22 | .. | .. | 21 | .. | .. | 20 | .. | 19 | .. | 18 | .. | .. | 17 | .. | .. | 16 |
| 38.0 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 31 | 30 | 29 | .. | 28 | .. | 27 | 26 | 26 | 25 | 25 | .. | 24 | .. | .. | 23 | .. | 22 | 22 | .. | 21 | 21 | .. | 20 | .. | 19 | .. | 18 | .. | .. | 17 | .. | .. |

NOTE:—Tables figured for C. I. pipes: for concrete ducts, friction is 50% more.

## TABLE V

### AIR DUCTS EQUALIZED FOR CONSTANT FRICTION (B. F. STURTEVANT CO.)

| FRICTION PER 100 FOOT OF PIPE IN INCHES OF WATER | | | | | | | | | | | | | Dia. in Ins. | CORRESPONDING RECTANGULAR DUCT | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .40 | .35 | .30 | .25 | .20 | .18 | .16 | .14 | .12 | .10 | .08 | .06 | .04 | | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| Cubic Feet of Air per Minute | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13600 | 12700 | 11700 | 10700 | 9590 | 9100 | 8580 | 8020 | 7430 | 6780 | 6070 | 5250 | 4290 | 31.0 | 63 | 58 | 53 | 49 | 46 | 43 | 41 | 39 | 37 | 35 | 33 | 32 | 31 | 29 | 28 | 27 | 26 | 26 | 25 | 24 | .. | 23 | 22 | 22 |
| 14100 | 13200 | 12200 | 11200 | 10100 | 9500 | 9000 | 8400 | 7700 | 7100 | 6300 | 5500 | 4500 | 31.5 | 65 | 60 | 55 | 51 | 48 | 45 | 42 | 40 | 38 | 36 | 34 | 33 | .. | 30 | 29 | 28 | 27 | .. | .. | 25 | 24 | .. | 23 | .. |
| 14700 | 13700 | 12700 | 11600 | 10400 | 9800 | 9300 | 8700 | 8000 | 7300 | 6500 | 5700 | 4600 | 32.0 | 68 | 62 | 57 | 53 | 49 | 46 | 44 | 41 | 39 | 37 | 36 | 34 | 33 | 31 | 30 | 29 | 28 | 27 | 26 | 26 | 25 | 24 | 24 | 23 |
| 15300 | 14300 | 13200 | 12100 | 10700 | 10200 | 9700 | 9000 | 8400 | 7600 | 6800 | 5900 | 4800 | 32.5 | 70 | 64 | 59 | 55 | 51 | 48 | 45 | 43 | 40 | 38 | 37 | 35 | 34 | 32 | 31 | 30 | 29 | 28 | 27 | .. | 26 | 25 | .. | 24 |
| 15900 | 14800 | 13700 | 12500 | 11100 | 10600 | 10000 | 9400 | 8700 | 7900 | 7100 | 6200 | 5000 | 33.0 | .. | 66 | 61 | 57 | 53 | 49 | 47 | 44 | 42 | 40 | 38 | 36 | 35 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | .. | 26 | 25 | .. |
| 16500 | 15400 | 14200 | 13000 | 11500 | 11000 | 10400 | 9700 | 9000 | 8200 | 7400 | 6400 | 5200 | 33.5 | .. | 69 | 63 | 59 | 55 | 51 | 48 | 45 | 43 | 41 | 39 | 37 | 36 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | .. | 26 | 25 |
| 17100 | 15900 | 14800 | 13500 | 12000 | 11400 | 10800 | 10100 | 9300 | 8500 | 7600 | 6600 | 5400 | 34.0 | .. | 71 | 65 | 61 | 56 | 53 | 50 | 47 | 45 | 42 | 40 | 39 | 37 | 36 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 27 | 26 |
| 17800 | 16600 | 15400 | 14000 | 12500 | 11900 | 11200 | 10500 | 9700 | 8900 | 7900 | 6900 | 5600 | 34.5 | .. | 74 | 67 | 63 | 58 | 54 | 51 | 49 | 46 | 44 | 42 | 40 | 38 | .. | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | .. | .. |
| 18400 | 17200 | 16000 | 14500 | 12900 | 12300 | 11700 | 10900 | 10100 | 9200 | 8200 | 7100 | 5800 | 35.0 | .. | .. | 70 | 65 | 60 | 56 | 53 | 50 | 47 | 45 | 43 | 41 | 39 | 38 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 |
| 19000 | 17700 | 16400 | 15000 | 13400 | 12700 | 12000 | 11200 | 10400 | 9500 | 8500 | 7300 | 6000 | 35.5 | .. | .. | 72 | 67 | 62 | 58 | 55 | 52 | 49 | 46 | 44 | 42 | 40 | 39 | 37 | 36 | 35 | .. | .. | .. | .. | 30 | 29 | 28 |
| 19700 | 18400 | 17100 | 15600 | 13800 | 13200 | 12500 | 11700 | 10800 | 9900 | 8800 | 7600 | 6200 | 36.0 | .. | .. | 74 | 69 | 64 | 60 | 56 | 53 | 50 | 48 | 46 | 44 | 42 | 40 | 38 | 37 | 36 | 34 | 33 | 32 | 31 | .. | 30 | 29 |
| 20400 | 19100 | 17700 | 15900 | 14300 | 13700 | 12500 | 12100 | 11200 | 10200 | 9100 | 7900 | 6500 | 36.5 | .. | .. | 77 | 71 | 66 | 62 | 58 | 55 | 52 | 49 | 47 | 45 | 43 | 41 | 40 | 38 | 37 | 35 | 34 | 33 | 32 | 31 | .. | 30 |
| 21100 | 19700 | 18300 | 16700 | 14800 | 14200 | 13400 | 12500 | 11600 | 10600 | 9500 | 8200 | 6700 | 37.0 | .. | .. | 79 | 73 | 68 | 64 | 60 | 57 | 54 | 50 | 48 | 46 | 44 | 42 | 41 | 39 | 38 | 37 | 35 | 34 | 33 | 32 | 31 | 31 |
| 21900 | 20400 | 18900 | 17300 | 15500 | 14700 | 13900 | 12900 | 12000 | 10900 | 9800 | 8500 | 6900 | 37.5 | .. | .. | 82 | 76 | 70 | 66 | 61 | 58 | 55 | 52 | 50 | 47 | 45 | 44 | 42 | 40 | 39 | .. | 36 | 35 | 34 | 33 | 32 | .. |
| 22600 | 21000 | 19500 | 17800 | 16000 | 15400 | 14300 | 13300 | 12300 | 11300 | 10100 | 8700 | 7100 | 38.0 | .. | .. | .. | 78 | 72 | 68 | 63 | 60 | 57 | 54 | 51 | 49 | 47 | 45 | 43 | 41 | 40 | 39 | 37 | 36 | 35 | 34 | 33 | 32 |
| 23300 | 21800 | 20200 | 18400 | 16500 | 15600 | 14700 | 13800 | 12800 | 11700 | 10400 | 9030 | 7370 | 38.5 | .. | .. | .. | 80 | 75 | 70 | 65 | 61 | 58 | 56 | 53 | 50 | 48 | 46 | 44 | 43 | 41 | 40 | 38 | 37 | 36 | 35 | 34 | 33 |
| 24100 | 22500 | 20900 | 19000 | 17000 | 16200 | 15200 | 14300 | 13200 | 12000 | 10800 | 9330 | 7620 | 39.0 | .. | .. | .. | 83 | 77 | 72 | 67 | 63 | 60 | 57 | 54 | 52 | 49 | 47 | 45 | 44 | 42 | 41 | 39 | 38 | 37 | 36 | 35 | 34 |
| 24900 | 23300 | 21500 | 19600 | 17600 | 16700 | 15700 | 14700 | 13600 | 12400 | 11100 | 9630 | 7860 | 39.5 | .. | .. | .. | 85 | 79 | 74 | 69 | 65 | 62 | 58 | 56 | 53 | 50 | 49 | 47 | 45 | 43 | 42 | 40 | 39 | 38 | 37 | 36 | 35 |
| 25600 | 24000 | 22200 | 20300 | 18100 | 17200 | 16200 | 15200 | 14000 | 12800 | 11500 | 9930 | 8110 | 40.0 | .. | .. | .. | .. | 81 | 76 | 71 | 67 | 64 | 60 | 57 | 55 | 52 | 50 | 48 | 46 | 44 | 43 | 42 | 40 | 39 | 38 | 37 | 36 |
| 26400 | 24700 | 22900 | 20900 | 18700 | 17700 | 16700 | 15600 | 14500 | 13200 | 11800 | 10200 | 8360 | 40.5 | .. | .. | .. | .. | 84 | 78 | 73 | 69 | 65 | 62 | 59 | 56 | 53 | 51 | 49 | 47 | 46 | 44 | .. | 41 | 40 | 39 | .. | .. |
| 27300 | 25500 | 23600 | 21600 | 19300 | 18300 | 17200 | 16100 | 14900 | 13600 | 12200 | 10600 | 8630 | 41.0 | .. | .. | .. | .. | 86 | 80 | 75 | 71 | 67 | 63 | 60 | 57 | 55 | 52 | 50 | 49 | 47 | 45 | 44 | 42 | 41 | 40 | 38 | 37 |
| 28100 | 26300 | 24400 | 22200 | 19900 | 18900 | 17800 | 16600 | 15400 | 14100 | 12600 | 10900 | 8890 | 41.5 | .. | .. | .. | .. | 89 | 83 | 77 | 73 | 69 | 65 | 62 | 59 | 56 | 54 | 52 | 50 | 48 | 46 | 45 | 43 | 42 | 41 | 39 | 38 |
| 29000 | 27100 | 25100 | 22900 | 20500 | 19400 | 18300 | 17100 | 15900 | 14500 | 13000 | 11200 | 9160 | 42.0 | .. | .. | .. | .. | 91 | 85 | 79 | 75 | 70 | 67 | 64 | 61 | 58 | 55 | 53 | 51 | 49 | 47 | 46 | 44 | 43 | 42 | 40 | 39 |
| 29900 | 27900 | 25900 | 23600 | 21100 | 20000 | 18900 | 17700 | 16400 | 14900 | 13400 | 11600 | 9440 | 42.5 | .. | .. | .. | .. | .. | 87 | 82 | 77 | 72 | 69 | 65 | 62 | 59 | 56 | 54 | 52 | 50 | 49 | 47 | 45 | 44 | 43 | 41 | 40 |
| 30700 | 28800 | 26600 | 24300 | 21700 | 20600 | 19400 | 18200 | 16800 | 15400 | 13800 | 11900 | 9730 | 43.0 | .. | .. | .. | .. | .. | 89 | 84 | 79 | 74 | 71 | 67 | 64 | 61 | 58 | 56 | 53 | 52 | 50 | 48 | 47 | 45 | 44 | 42 | 41 |
| 31700 | 29600 | 27400 | 25000 | 22400 | 21200 | 20000 | 18700 | 17300 | 15800 | 14200 | 12300 | 10000 | 43.5 | .. | .. | .. | .. | .. | 92 | 86 | 81 | 76 | 72 | 69 | 65 | 62 | 59 | 57 | 55 | 53 | 51 | 49 | 48 | 46 | 45 | 43 | 42 |
| 32600 | 30500 | 28200 | 25800 | 23000 | 21900 | 20600 | 19300 | 17800 | 16300 | 14600 | 12600 | 10300 | 44.0 | .. | .. | .. | .. | .. | 94 | 88 | 83 | 78 | 74 | 70 | 67 | 63 | 61 | 58 | 56 | 54 | 52 | 50 | 49 | 47 | 46 | 44 | 43 |
| 33500 | 31400 | 29000 | 26500 | 23700 | 22500 | 21200 | 19800 | 18400 | 16800 | 15000 | 13000 | 10600 | 44.5 | .. | .. | .. | .. | .. | 97 | 91 | 85 | 80 | 76 | 72 | 69 | 65 | 63 | 60 | 58 | 56 | 53 | 52 | 50 | 48 | 47 | 45 | 44 |
| 34500 | 32300 | 29900 | 27200 | 24400 | 23200 | 21800 | 20400 | 18900 | 17300 | 15500 | 13400 | 10900 | 45.0 | .. | .. | .. | .. | .. | .. | 93 | 87 | 82 | 78 | 74 | 70 | 67 | 64 | 61 | 59 | 57 | 55 | 53 | 51 | 50 | 48 | 47 | 45 |
| 35500 | 33200 | 30700 | 28100 | 25100 | 23800 | 22200 | 21000 | 19400 | 17700 | 15900 | 13700 | 11200 | 45.5 | .. | .. | .. | .. | .. | .. | 95 | 90 | 84 | 80 | 76 | 72 | 69 | 66 | 63 | 61 | 58 | 56 | 54 | 52 | 51 | 50 | 48 | 46 |
| 36500 | 34100 | 31500 | 28800 | 25800 | 24400 | 23000 | 21500 | 19900 | 18200 | 16300 | 14000 | 11500 | 46.0 | .. | .. | .. | .. | .. | .. | 97 | 92 | 87 | 82 | 78 | 74 | 70 | 67 | 64 | 62 | 59 | 57 | 55 | 54 | 52 | 51 | 49 | 47 |
| 37400 | 34900 | 32300 | 29600 | 26400 | 25100 | 23600 | 22200 | 20500 | 18700 | 16700 | 14500 | 11800 | 46.5 | .. | .. | .. | .. | .. | .. | 100 | 94 | 89 | 84 | 80 | 76 | 72 | 69 | 66 | 63 | 61 | 59 | 57 | 55 | 53 | 52 | 50 | 48 |
| 38500 | 36100 | 33400 | 30500 | 27300 | 25900 | 24400 | 22900 | 21100 | 19300 | 17200 | 14900 | 12200 | 47.0 | .. | .. | .. | .. | .. | .. | .. | 95 | 91 | 87 | 82 | 78 | 74 | 70 | 67 | 65 | 62 | 60 | 58 | 56 | 54 | 53 | 51 | 49 |
| 39500 | 36900 | 34200 | 31200 | 27900 | 26400 | 25000 | 23300 | 21600 | 19700 | 17600 | 15300 | 12500 | 47.5 | .. | .. | .. | .. | .. | .. | .. | 99 | 93 | 88 | 84 | 79 | 76 | 72 | 69 | 66 | 64 | 61 | 59 | 57 | 55 | 54 | 52 | 51 |
| 40700 | 37900 | 35100 | 32100 | 28700 | 27300 | 25700 | 24000 | 22200 | 20300 | 18100 | 15700 | 12800 | 48.0 | .. | .. | .. | .. | .. | .. | .. | 101 | 95 | 90 | 86 | 81 | 78 | 74 | 71 | 68 | 65 | 63 | 61 | 58 | 56 | 55 | 53 | 52 |
| 41600 | 39000 | 35900 | 32900 | 29400 | 27800 | 26200 | 24600 | 22800 | 20800 | 18600 | 16100 | 13200 | 48.5 | .. | .. | .. | .. | .. | .. | .. | 104 | 97 | 92 | 88 | 83 | 79 | 75 | 72 | 69 | 67 | 64 | 62 | 60 | 58 | 56 | 54 | 53 |
| 42500 | 39800 | 36900 | 33700 | 30100 | 28600 | 26900 | 25200 | 23300 | 21300 | 19100 | 16500 | 13500 | 49.0 | .. | .. | .. | .. | .. | .. | .. | 106 | 100 | 94 | 90 | 85 | 81 | 77 | 74 | 71 | 68 | 66 | 63 | 61 | 59 | 57 | 55 | 54 |
| 43800 | 41000 | 37900 | 34600 | 31000 | 29400 | 27700 | 25900 | 24000 | 21900 | 19600 | 17000 | 13900 | 49.5 | .. | .. | .. | .. | .. | .. | .. | .. | 102 | 96 | 92 | 87 | 83 | 79 | 76 | 72 | 70 | 67 | 65 | 63 | 60 | 59 | 56 | 55 |
| 44800 | 42000 | 38800 | 35400 | 31700 | 30000 | 28400 | 26500 | 24600 | 22400 | 20000 | 17400 | 14200 | 50.0 | .. | .. | .. | .. | .. | .. | .. | .. | 105 | 98 | 94 | 89 | 85 | 81 | 77 | 74 | 72 | 68 | 66 | 64 | 61 | 60 | 58 | 56 |
| 45800 | 43300 | 39900 | 36300 | 32500 | 30900 | 29100 | 27200 | 25100 | 23000 | 20600 | 17800 | 14500 | 50.5 | .. | .. | .. | .. | .. | .. | .. | .. | 107 | 102 | 96 | 91 | 87 | 83 | 79 | 76 | 73 | 70 | 68 | 66 | 63 | 61 | 59 | 57 |
| 47600 | 44400 | 41200 | 37500 | 33600 | 31900 | 30000 | 28100 | 26000 | 23800 | 21300 | 18400 | 15000 | 51.0 | .. | .. | .. | .. | .. | .. | .. | .. | 110 | 104 | 98 | 93 | 89 | 85 | 81 | 77 | 74 | 71 | 69 | 67 | 64 | 62 | 61 | 59 |
| 48400 | 45200 | 41800 | 38200 | 34200 | 32400 | 30500 | 28600 | 26500 | 24200 | 21600 | 18700 | 15300 | 51.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 106 | 100 | 95 | 90 | 86 | 82 | 79 | 76 | 73 | 70 | 68 | 66 | 64 | 62 | 60 |
| 49700 | 46500 | 42900 | 39200 | 35100 | 33300 | 31400 | 29400 | 27200 | 24800 | 22200 | 19200 | 15700 | 52.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 108 | 103 | 97 | 92 | 88 | 84 | 81 | 78 | 75 | 72 | 69 | 67 | 65 | 63 | 61 |
| 50600 | 47400 | 43800 | 40000 | 35700 | 33900 | 32000 | 29900 | 27700 | 25300 | 22600 | 19600 | 16000 | 52.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 111 | 105 | 99 | 95 | 90 | 86 | 82 | 79 | 76 | 74 | 70 | 68 | 66 | 64 | 62 |
| 51800 | 48500 | 44900 | 41000 | 36700 | 34800 | 32800 | 30700 | 28400 | 25900 | 23200 | 20100 | 16400 | 53.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 113 | 107 | 102 | 97 | 92 | 88 | 84 | 81 | 78 | 75 | 72 | 70 | 68 | 66 | 64 |
| 53000 | 49700 | 45900 | 42000 | 37600 | 35700 | 33600 | 31500 | 29100 | 26600 | 23800 | 20600 | 16800 | 53.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 116 | 109 | 103 | 99 | 94 | 90 | 86 | 82 | 80 | 76 | 74 | 72 | 69 | 67 | 65 |
| 54300 | 50800 | 47000 | 43000 | 38400 | 36500 | 34400 | 32200 | 29800 | 27200 | 24300 | 21100 | 17200 | 54.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 112 | 106 | 101 | 96 | 92 | 88 | 84 | 81 | 78 | 75 | 73 | 70 | 68 | 66 |
| 55600 | 52000 | 48200 | 44000 | 39300 | 37400 | 35200 | 32900 | 30500 | 27800 | 24800 | 21600 | 17600 | 54.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 114 | 108 | 103 | 98 | 94 | 90 | 86 | 83 | 80 | 77 | 74 | 72 | 70 | 67 |
| 56900 | 53200 | 49300 | 45000 | 40200 | 38200 | 36000 | 33700 | 31200 | 28400 | 25400 | 22000 | 18000 | 55.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 117 | 111 | 105 | 100 | 96 | 92 | 88 | 84 | 82 | 78 | 76 | 73 | 71 | 69 |
| 58200 | 54400 | 50400 | 46000 | 41200 | 39000 | 36800 | 34400 | 31900 | 29000 | 26000 | 22500 | 18400 | 55.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 113 | 107 | 102 | 98 | 93 | 90 | 86 | 83 | 80 | 77 | 75 | 72 | 70 |
| 59900 | 56000 | 51800 | 47300 | 42200 | 40000 | 37800 | 35300 | 32800 | 29900 | 26700 | 23100 | 18900 | 56.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 121 | 115 | 110 | 104 | 100 | 95 | 91 | 88 | 85 | 82 | 79 | 76 | 74 | 71 |
| 61000 | 57000 | 52700 | 48200 | 43000 | 40800 | 38500 | 36000 | 33300 | 30400 | 27200 | 23600 | 19200 | 56.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 112 | 107 | 102 | 97 | 93 | 90 | 86 | 84 | 80 | 78 | 75 | 73 |
| 62200 | 58200 | 53900 | 49300 | 44000 | 41700 | 39400 | 36800 | 34000 | 31100 | 27800 | 24100 | 19700 | 57.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 114 | 109 | 104 | 99 | 95 | 91 | 88 | 85 | 82 | 79 | 77 | 74 |
| 63500 | 59400 | 55000 | 50300 | 45000 | 42600 | 40300 | 37700 | 34800 | 31800 | 28500 | 24600 | 20100 | 57.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 116 | 111 | 106 | 101 | 97 | 93 | 90 | 86 | 83 | 81 | 78 | 76 |

NOTE:—Tables figured for C. I. pipes: for concrete ducts, friction is 50% more.

## TABLE VI

### AIR DUCTS EQUALIZED FOR CONSTANT FRICTION (B. F. STURTEVANT CO.)

| Dia. In Inches | CORRESPONDING RECTANGULAR DUCT | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 | 92 | 94 | 96 | 98 | 100 |
| 38.5 | 32 | .. | 31 | 30 | 29 | 29 | 28 | .. | 27 | .. | 26 | .. | 25 | .. | 24 | 24 | .. | 23 | 23 | .. | 22 | .. | .. | 21 | .. | 20 | .. | 19 | .. | 18 | .. | .. | 17 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 39.0 | 33 | 32 | .. | 31 | 30 | .. | 29 | 28 | .. | 27 | .. | 26 | .. | 25 | 25 | .. | 24 | .. | .. | 23 | .. | 22 | 22 | .. | 21 | .. | 20 | .. | 19 | .. | 18 | .. | .. | 17 | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 39.5 | 34 | 33 | 32 | .. | 31 | 30 | .. | 29 | 28 | 28 | 27 | 27 | 26 | 26 | .. | 25 | .. | 24 | 24 | .. | 23 | 23 | .. | 22 | .. | .. | .. | 20 | .. | 19 | .. | 18 | 18 | .. | 17 | 17 | .. | .. | .. | .. | .. | .. | .. |
| 40.0 | 35 | 34 | 33 | 32 | 32 | 31 | 30 | .. | 29 | .. | 28 | .. | 27 | .. | 26 | .. | 25 | 25 | .. | 24 | .. | .. | 23 | .. | 22 | 21 | .. | .. | 20 | .. | 19 | .. | .. | 18 | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 40.5 | .. | 35 | 34 | 33 | .. | .. | 31 | 30 | 30 | 29 | .. | 28 | .. | 27 | .. | 26 | 26 | .. | 25 | .. | 24 | 24 | .. | 23 | .. | .. | 21 | .. | .. | 20 | .. | 19 | .. | .. | 18 | .. | .. | .. | .. | .. | .. | .. | .. |
| 41.0 | 36 | .. | 35 | 34 | 33 | 32 | 32 | 31 | .. | 30 | 29 | 29 | 28 | .. | 27 | 27 | .. | 26 | .. | 25 | 25 | .. | 24 | .. | 23 | 22 | .. | 21 | .. | .. | 20 | .. | 19 | .. | .. | 18 | .. | .. | .. | .. | .. | .. | .. |
| 41.5 | 37 | 36 | .. | 35 | 34 | 33 | .. | 32 | 31 | .. | 30 | .. | 29 | 28 | 28 | .. | 27 | .. | 26 | .. | .. | 25 | .. | 24 | .. | .. | 22 | .. | 21 | .. | .. | .. | .. | 19 | .. | .. | 18 | .. | .. | .. | .. | .. | .. |
| 42.0 | 38 | 37 | 36 | .. | 35 | 34 | 33 | .. | 32 | 31 | .. | 30 | .. | 29 | .. | 28 | .. | 27 | .. | 26 | 26 | .. | 25 | .. | 24 | 23 | .. | 22 | .. | 21 | .. | 20 | 20 | .. | 19 | .. | .. | 18 | 18 | .. | .. | .. | .. |
| 42.5 | 39 | 38 | 37 | 36 | .. | 35 | 34 | 33 | .. | 32 | 31 | 31 | 30 | .. | 29 | .. | 28 | 28 | 27 | 27 | .. | 26 | .. | 25 | .. | .. | 23 | .. | 22 | .. | 21 | .. | .. | 20 | .. | 19 | 19 | .. | .. | .. | .. | .. | .. |
| 43.0 | 40 | 39 | 38 | 37 | 36 | .. | 35 | 34 | 33 | 33 | 32 | .. | 31 | 30 | 30 | 29 | 29 | .. | 28 | .. | 27 | .. | 26 | .. | 25 | 24 | .. | 23 | .. | 22 | .. | 21 | .. | .. | 20 | .. | .. | 19 | .. | .. | .. | .. | .. |
| 43.5 | 41 | 40 | 39 | 38 | 37 | 36 | .. | 35 | 34 | .. | 33 | 32 | .. | 31 | .. | 30 | .. | 29 | .. | 28 | .. | 27 | 27 | 26 | .. | 25 | 24 | .. | 23 | .. | 22 | .. | 21 | .. | .. | 20 | .. | .. | 19 | .. | .. | .. | .. |
| 44.0 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | .. | 35 | 34 | .. | 33 | 32 | .. | 31 | .. | 30 | .. | 29 | .. | 28 | 28 | .. | .. | 26 | .. | .. | 24 | .. | 23 | .. | 22 | .. | 21 | 21 | .. | 20 | .. | .. | 19 | .. | .. | .. |
| 44.5 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | .. | 35 | 34 | .. | 33 | 32 | 32 | 31 | 31 | 30 | 30 | 29 | 29 | .. | 28 | 27 | .. | 26 | 25 | .. | 24 | .. | 23 | .. | 22 | .. | .. | 21 | .. | 20 | .. | .. | 19 | 19 | .. |
| 45.0 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 36 | 35 | 34 | 34 | 33 | .. | 32 | .. | 31 | .. | 30 | .. | 29 | .. | 28 | 27 | .. | .. | 25 | .. | 24 | .. | 23 | .. | 22 | .. | .. | 21 | .. | 20 | 20 | .. | .. | .. |
| 45.5 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | .. | 36 | 35 | 35 | 34 | 33 | .. | 32 | .. | 31 | .. | 30 | .. | 29 | .. | .. | 27 | 26 | .. | 25 | .. | 24 | .. | 23 | .. | 22 | .. | .. | 21 | .. | .. | 20 | .. | .. |
| 46.0 | 46 | 45 | 44 | 43 | .. | 41 | 40 | 39 | 38 | 37 | .. | 36 | .. | 35 | 34 | 33 | 33 | 32 | .. | 31 | .. | 30 | 30 | 29 | 28 | .. | 27 | 26 | .. | 25 | .. | 24 | .. | 23 | .. | 22 | .. | .. | 21 | .. | .. | 20 | .. |
| 46.5 | 47 | 46 | 45 | .. | 42 | .. | .. | 40 | 39 | 38 | 37 | .. | 36 | .. | 35 | 34 | .. | 33 | 32 | 32 | 31 | 31 | .. | .. | 29 | 28 | .. | .. | 26 | .. | 25 | .. | 24 | .. | 23 | .. | 22 | .. | .. | 21 | .. | .. | 20 |
| 47.0 | 48 | 47 | 46 | 44 | 43 | 42 | 41 | .. | 40 | 39 | 38 | 37 | 37 | 36 | .. | 35 | 34 | .. | 33 | .. | 32 | .. | 31 | 30 | .. | .. | 28 | 27 | .. | 26 | .. | 25 | .. | 24 | .. | 23 | .. | 22 | .. | .. | 21 | .. | .. |
| 47.5 | 49 | 48 | 47 | 45 | 44 | 43 | 42 | 41 | .. | 40 | 39 | 38 | 38 | 37 | 36 | .. | 35 | 34 | .. | 33 | .. | 32 | .. | 31 | 30 | 29 | .. | .. | 27 | .. | 26 | .. | 25 | .. | 24 | .. | 23 | .. | 22 | 22 | .. | 21 | 21 |
| 48.0 | 50 | 49 | 48 | 46 | 45 | 44 | 43 | 42 | 41 | .. | 40 | 39 | .. | .. | 37 | 36 | .. | 35 | 34 | 34 | 33 | 33 | 32 | .. | .. | .. | 29 | 28 | .. | 27 | .. | 26 | .. | 25 | .. | 24 | .. | 23 | .. | .. | 22 | .. | .. |
| 48.5 | 51 | 50 | 49 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | .. | 40 | 39 | 38 | .. | 37 | 36 | .. | 35 | .. | 34 | .. | 33 | 32 | 31 | 30 | .. | 29 | 28 | .. | 27 | .. | 26 | .. | .. | .. | 24 | .. | 23 | .. | .. | 22 | .. |
| 49.0 | 52 | 51 | 50 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | .. | 40 | 39 | 38 | .. | 37 | 36 | .. | 35 | .. | 34 | .. | .. | .. | 31 | 30 | .. | .. | 28 | .. | 27 | .. | .. | 25 | .. | .. | 24 | .. | 23 | .. | .. | 22 |
| 49.5 | 54 | 52 | 51 | 49 | 48 | 47 | 46 | .. | 44 | 43 | 42 | 41 | .. | 40 | 39 | 38 | 38 | 37 | 36 | 36 | 35 | 35 | 34 | 33 | 32 | .. | .. | 30 | 29 | .. | 28 | .. | .. | 26 | .. | 25 | .. | .. | 24 | .. | 23 | .. | .. |
| 50.0 | 55 | 53 | 52 | 50 | .. | 48 | 47 | 45 | .. | 44 | 43 | .. | 41 | .. | 40 | 39 | .. | 38 | 37 | .. | 36 | .. | 35 | 34 | 33 | 32 | 31 | .. | 30 | 29 | .. | 28 | 27 | .. | 26 | .. | 25 | .. | .. | 24 | .. | 23 | .. |
| 50.5 | 56 | 54 | 53 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | .. | 40 | 39 | .. | 38 | 37 | .. | 36 | .. | .. | .. | 33 | 32 | 31 | .. | .. | 29 | .. | .. | 27 | .. | 26 | .. | 25 | .. | .. | 24 | .. | 23 |
| 51.0 | 57 | 55 | 54 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | .. | 40 | 39 | .. | 38 | 37 | 37 | 36 | 35 | 34 | .. | .. | .. | 31 | 30 | .. | 29 | 28 | .. | 27 | .. | 26 | .. | 25 | 25 | .. | 24 | .. |
| 51.5 | 58 | 57 | 55 | 53 | 52 | 51 | 50 | 49 | 48 | .. | 46 | 45 | 44 | 43 | 42 | 41 | .. | 40 | 39 | 39 | 38 | .. | 37 | 36 | 35 | 34 | 33 | 32 | .. | .. | 30 | .. | .. | 28 | .. | 27 | .. | 26 | .. | .. | 25 | .. | 24 |
| 52.0 | 59 | 58 | 56 | 55 | 53 | 52 | 51 | 50 | .. | 47 | .. | .. | 45 | 44 | 43 | 42 | 41 | 41 | 40 | .. | 39 | 38 | .. | .. | .. | .. | .. | .. | 32 | 31 | .. | 30 | 29 | .. | 28 | .. | 27 | .. | 26 | .. | .. | 25 | .. |
| 52.5 | 60 | 59 | 57 | 56 | 54 | 53 | 52 | 51 | 49 | 48 | 47 | 46 | .. | 45 | 44 | 43 | 42 | .. | 41 | 40 | .. | 39 | 38 | 37 | 36 | 35 | 34 | 33 | .. | 32 | 31 | .. | 30 | 29 | .. | 28 | .. | 27 | .. | 26 | .. | .. | 25 |
| 53.0 | 62 | 60 | 58 | 57 | 55 | 54 | 53 | .. | 50 | 49 | 48 | 47 | 46 | .. | .. | 44 | 43 | 42 | .. | 41 | 40 | .. | 39 | 38 | 37 | 36 | 35 | 34 | 33 | .. | .. | 31 | .. | .. | 29 | .. | 28 | .. | 27 | .. | 26 | .. | .. |
| 53.5 | 63 | 61 | 59 | 58 | 56 | 55 | 54 | 53 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 45 | 44 | 43 | 42 | .. | 41 | 40 | .. | .. | .. | .. | .. | .. | 34 | 33 | 32 | .. | 31 | 30 | .. | 29 | .. | 28 | .. | 27 | .. | 26 | .. |
| 54.0 | 64 | 62 | 61 | 59 | 58 | 56 | 55 | .. | 52 | 51 | 50 | 49 | 48 | 47 | 46 | .. | .. | 44 | 43 | 42 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | .. | .. | 33 | 32 | .. | .. | 30 | .. | 29 | .. | 28 | .. | 27 | .. | 26 |
| 54.5 | 65 | 64 | 62 | 60 | 59 | 57 | 56 | 55 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 45 | 44 | 43 | .. | 42 | 41 | 40 | 39 | .. | .. | 36 | 35 | 34 | .. | .. | 32 | 31 | .. | 30 | .. | 29 | .. | 28 | .. | 27 | .. |
| 55.0 | 67 | 65 | 63 | 61 | 60 | 58 | 57 | 56 | 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | .. | 45 | 44 | 43 | .. | 42 | .. | .. | 38 | 37 | .. | .. | .. | 34 | 33 | .. | 32 | 31 | .. | 30 | .. | 29 | .. | 28 | .. | 27 |
| 55.5 | 68 | 66 | 64 | 63 | 61 | 59 | 58 | 57 | 55 | 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | .. | 45 | 44 | 43 | .. | 41 | 40 | 39 | 38 | 37 | 36 | 35 | .. | .. | 33 | .. | .. | 31 | .. | 30 | .. | 29 | .. | 28 | .. |
| 56.0 | 69 | 67 | 66 | 64 | 62 | 60 | 59 | 58 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | .. | 45 | 44 | 43 | 42 | 41 | 40 | .. | .. | 37 | 36 | 35 | 34 | .. | 33 | 32 | .. | 31 | .. | 30 | .. | 29 | .. | 28 |
| 56.5 | 71 | 69 | 67 | 65 | 63 | 62 | 60 | 59 | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | .. | 45 | 44 | 43 | .. | .. | 39 | 38 | .. | .. | .. | 35 | 34 | .. | .. | 32 | .. | 31 | .. | 30 | .. | 29 | .. |
| 57.0 | 73 | 70 | 68 | 66 | 64 | 63 | 61 | 60 | 58 | 57 | 56 | 55 | 54 | .. | .. | .. | 50 | 49 | 48 | 47 | 46 | .. | 45 | .. | 42 | 41 | 40 | 39 | 38 | 37 | 36 | .. | .. | 34 | 33 | .. | 32 | .. | 31 | .. | 30 | .. | 29 |
| 57.5 | 74 | 71 | 69 | 67 | 66 | 64 | 62 | 61 | 59 | 58 | 57 | 56 | 55 | 53 | 52 | 51 | .. | 50 | 49 | 48 | 47 | 46 | .. | 44 | 43 | 42 | 41 | .. | .. | 38 | 37 | 36 | 35 | .. | 34 | 33 | .. | 32 | .. | .. | .. | .. | .. |
| 58.0 | 75 | 72 | 71 | 69 | 67 | 65 | 64 | 62 | 60 | 59 | 58 | 57 | .. | 54 | 53 | 52 | 51 | .. | .. | 49 | 48 | 47 | 46 | 45 | 44 | .. | .. | 40 | 39 | .. | .. | .. | 36 | 35 | .. | .. | 33 | .. | 32 | 31 | .. | 30 | .. |
| 58.5 | 76 | 74 | 72 | 70 | 68 | 66 | 65 | 63 | 62 | 60 | 59 | 58 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | .. | 49 | 48 | 47 | 46 | .. | 43 | 42 | 41 | 40 | 39 | 38 | 37 | .. | .. | 35 | 34 | .. | 33 | .. | .. | 31 | .. | 30 |
| 59.0 | 77 | 75 | 73 | 71 | 69 | 68 | 66 | 64 | 63 | 61 | 60 | 59 | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | .. | 49 | 48 | .. | 45 | 44 | 43 | .. | .. | .. | .. | 38 | 37 | 36 | .. | 35 | 34 | .. | 33 | 32 | .. | 31 | .. |
| 59.5 | 79 | 77 | 74 | 72 | 70 | 69 | 67 | 65 | 64 | 62 | 61 | 60 | 58 | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | .. | 49 | 47 | 46 | .. | .. | 42 | 41 | 40 | 39 | .. | .. | .. | 36 | .. | .. | 34 | .. | 33 | 32 | .. | 31 |
| 60.0 | 80 | 78 | 76 | 74 | 72 | 70 | 68 | 67 | 65 | 64 | 62 | 61 | 59 | 58 | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | .. | 48 | 47 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | .. | 36 | 35 | .. | 34 | .. | .. | 32 | .. |
| 60.5 | 82 | 79 | 77 | 75 | 73 | 71 | 69 | 68 | 66 | 65 | 63 | 62 | 60 | 59 | 58 | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | 49 | .. | 46 | 45 | .. | .. | .. | .. | .. | .. | 38 | 37 | .. | .. | 35 | .. | 34 | 33 | .. | 32 |
| 61.0 | 83 | 81 | 79 | 76 | 74 | 72 | 71 | 69 | 67 | 66 | 64 | 63 | 62 | 60 | 59 | 58 | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | 48 | 47 | .. | 44 | 43 | 42 | 41 | 40 | 39 | .. | .. | 37 | 36 | .. | 35 | 34 | .. | 33 | .. |
| 61.5 | 85 | 82 | 80 | 78 | 76 | 74 | 72 | 70 | 68 | 67 | 65 | 64 | 63 | 61 | 60 | 59 | 58 | 57 | 56 | 55 | 54 | 53 | 52 | .. | 49 | .. | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | .. | .. | 36 | .. | 35 | 34 | .. | 33 |
| 62.0 | 86 | 84 | 81 | 79 | 77 | 75 | 73 | 71 | 70 | 68 | 66 | 65 | 64 | 62 | 61 | 60 | 59 | 58 | 57 | 56 | 55 | 54 | 53 | 51 | 50 | 48 | 47 | 46 | .. | .. | .. | .. | .. | 40 | 39 | 38 | 37 | .. | 36 | .. | .. | 34 | .. |
| 62.5 | 88 | 85 | 83 | 80 | 78 | 76 | 74 | 72 | 71 | 69 | 67 | 66 | 65 | 63 | 62 | 61 | 60 | .. | .. | .. | .. | .. | 54 | 52 | .. | 49 | .. | .. | 45 | 44 | 43 | 42 | 41 | .. | .. | .. | 38 | 37 | .. | 36 | 35 | .. | 34 |
| 63.0 | 89 | 87 | 84 | 82 | 80 | 77 | 76 | 74 | 72 | 70 | 69 | 67 | 66 | 64 | 63 | 62 | 61 | 60 | 58 | 57 | 56 | 55 | 55 | 53 | 51 | 50 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | .. | .. | 37 | .. | .. | 35 | .. |
| 63.5 | 91 | 88 | 86 | 83 | 81 | 79 | 77 | 75 | 73 | 71 | 70 | 68 | 67 | 65 | 64 | 63 | 62 | .. | 59 | 58 | 57 | 56 | .. | 54 | 52 | .. | 49 | 48 | .. | .. | .. | .. | .. | .. | .. | 40 | 39 | 38 | .. | 37 | 36 | .. | 35 |
| 64.0 | 92 | 89 | 87 | 85 | 82 | 80 | 78 | 76 | 74 | 73 | 71 | 69 | 68 | 66 | 65 | 64 | 63 | 61 | 60 | 59 | 58 | 57 | 56 | .. | 53 | 51 | 50 | .. | 47 | 46 | 45 | 44 | 43 | 42 | 41 | .. | .. | 39 | 38 | .. | 37 | 36 | .. |
| 64.5 | 94 | 91 | 89 | 86 | 84 | 81 | 79 | 77 | 76 | 74 | 72 | 70 | 69 | 67 | 66 | 65 | 64 | 62 | 61 | 60 | 59 | 58 | 57 | 55 | 54 | 52 | .. | 49 | 48 | 47 | 46 | .. | .. | .. | 42 | 41 | 40 | .. | .. | 38 | .. | .. | 36 |
| 65.0 | 96 | 93 | 90 | 87 | 85 | 83 | 81 | 79 | 77 | 75 | 73 | 72 | 70 | 69 | 67 | 66 | 65 | 63 | 62 | 61 | 60 | 59 | 58 | 56 | .. | 53 | 51 | 50 | 49 | .. | .. | 45 | 44 | 43 | .. | .. | 41 | 40 | 39 | .. | 38 | 37 | .. |

NOTE:—Tables figured for C. I. pipes: for concrete ducts, friction is 50% more.

## TABLE VII

### AIR DUCTS EQUALIZED FOR CONSTANT FRICTION (B. F. STURTEVANT CO.)

| FRICTION PER 100 FT. PIPE IN INCHES OF WATER | | | | | | | | | | | | | Dia. in Ins. | CORRESPONDING RECTANGULAR DUCT | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .40 | .35 | .30 | .25 | .20 | .18 | .16 | .14 | .12 | .10 | .08 | .06 | .04 | | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 |
| Cubic Feet of Air per Minute | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 65000 | 60800 | 56300 | 51500 | 46000 | 43600 | 41100 | 38500 | 35600 | 32500 | 29100 | 25200 | 20600 | 58.0 | 119 | 113 | 108 | 103 | 99 | 95 | 91 | 88 | 85 | 82 | 79 | 77 | 75 | 72 | 71 | 69 | 67 | 65 | 64 | 62 | 60 |
| 66300 | 62100 | 57500 | 52600 | 47000 | 44500 | 42000 | 39300 | 36400 | 33200 | 29700 | 25800 | 21000 | 58.5 | 121 | 115 | 110 | 105 | 101 | 97 | 93 | 90 | 86 | 84 | 81 | 78 | 76 | 74 | 72 | 70 | 68 | 66 | 65 | 63 | 62 |
| 67900 | 63600 | 58800 | 53700 | 48000 | 45500 | 42900 | 40200 | 37200 | 33900 | 30400 | 26400 | 21500 | 59.0 | . . | 118 | 112 | 107 | 103 | 99 | 95 | 91 | 88 | 85 | 83 | 80 | 77 | 75 | 73 | 71 | 69 | 68 | 66 | 64 | 63 |
| 69200 | 64900 | 59900 | 54700 | 48800 | 46400 | 43700 | 40900 | 37900 | 34600 | 30900 | 26800 | 21900 | 59.5 | . . | 120 | 114 | 109 | 105 | 101 | 97 | 93 | 90 | 87 | 84 | 81 | 79 | 77 | 74 | 72 | 70 | 69 | 67 | 65 | 64 |
| 70700 | 66200 | 61300 | 55900 | 50000 | 47400 | 44700 | 41800 | 38800 | 35400 | 31600 | 27400 | 22400 | 60.0 | . . | . . | 117 | 111 | 107 | 103 | 99 | 95 | 92 | 88 | 86 | 83 | 80 | 78 | 76 | 74 | 72 | 70 | 68 | 67 | 65 |
| 72300 | 67700 | 62600 | 57200 | 51100 | 48400 | 45700 | 42800 | 39600 | 36100 | 32300 | 28000 | 22900 | 60.5 | . . | . . | 119 | 114 | 109 | 104 | 100 | 97 | 93 | 90 | 87 | 84 | 82 | 79 | 77 | 75 | 73 | 71 | 69 | 68 | 66 |
| 73600 | 68900 | 63800 | 58400 | 52200 | 49400 | 46600 | 43600 | 40400 | 36800 | 32900 | 28500 | 23300 | 61.0 | . . | . . | 121 | 116 | 111 | 106 | 102 | 98 | 95 | 92 | 89 | 86 | 83 | 81 | 79 | 76 | 74 | 72 | 71 | 69 | 67 |
| 75000 | 70200 | 65000 | 59400 | 53100 | 50300 | 47500 | 44400 | 41200 | 37500 | 33600 | 29100 | 23800 | 61.5 | . . | . . | . . | 118 | 113 | 108 | 104 | 100 | 97 | 93 | 90 | 87 | 85 | 82 | 80 | 78 | 76 | 74 | 72 | 70 | 68 |
| 76800 | 71800 | 66400 | 60600 | 54200 | 51200 | 48600 | 45400 | 42000 | 38400 | 34400 | 29700 | 24300 | 62.0 | . . | . . | . . | 120 | 115 | 110 | 106 | 102 | 98 | 95 | 92 | 89 | 86 | 84 | 81 | 79 | 77 | 75 | 73 | 71 | 70 |
| 78500 | 73400 | 67900 | 61900 | 55400 | 52600 | 49700 | 46400 | 43000 | 39200 | 35100 | 30300 | 24800 | 62.5 | . . | . . | . . | . . | 117 | 112 | 108 | 104 | 100 | 97 | 93 | 90 | 88 | 85 | 83 | 80 | 78 | 76 | 74 | 72 | 71 |
| 80100 | 75000 | 69400 | 63200 | 56600 | 53700 | 50700 | 47400 | 43900 | 40000 | 35800 | 31000 | 25300 | 63.0 | . . | . . | . . | . . | 119 | 114 | 110 | 106 | 102 | 98 | 95 | 92 | 89 | 87 | 84 | 82 | 80 | 77 | 76 | 74 | 72 |
| 81600 | 76500 | 70700 | 64500 | 57700 | 54700 | 51600 | 48300 | 44700 | 40800 | 36500 | 31600 | 25800 | 63.5 | . . | . . | . . | . . | 121 | 116 | 112 | 108 | 104 | 100 | 97 | 94 | 91 | 88 | 86 | 83 | 81 | 79 | 77 | 75 | 73 |
| 83000 | 77700 | 71900 | 65600 | 58700 | 55600 | 52400 | 49100 | 45400 | 41500 | 37100 | 32100 | 26200 | 64.0 | . . | . . | . . | . . | . . | 119 | 114 | 110 | 106 | 102 | 98 | 95 | 92 | 89 | 87 | 85 | 82 | 80 | 78 | 76 | 74 |
| 84600 | 79200 | 73200 | 67000 | 60000 | 56900 | 53600 | 50200 | 46400 | 42400 | 37900 | 32800 | 26800 | 64.5 | . . | . . | . . | . . | . . | 121 | 116 | 112 | 108 | 104 | 101 | 97 | 94 | 91 | 89 | 86 | 84 | 81 | 79 | 77 | 76 |
| 86400 | 80800 | 74700 | 68300 | 61100 | 58000 | 54600 | 51100 | 47300 | 43200 | 38600 | 33400 | 27300 | 65.0 | . . | . . | . . | . . | . . | . . | 118 | 113 | 109 | 105 | 102 | 99 | 96 | 93 | 90 | 87 | 85 | 83 | 81 | 79 | 77 |
| 88000 | 82400 | 76300 | 69600 | 62300 | 59000 | 55600 | 52100 | 48200 | 44000 | 39400 | 34100 | 27800 | 65.5 | . . | . . | . . | . . | . . | . . | 120 | 115 | 111 | 107 | 104 | 101 | 97 | 94 | 92 | 89 | 86 | 84 | 82 | 80 | 78 |
| 89300 | 83600 | 77300 | 70600 | 63200 | 59800 | 56400 | 52800 | 48900 | 44600 | 39900 | 34600 | 28200 | 66.0 | . . | . . | . . | . . | . . | . . | . . | 117 | 113 | 109 | 105 | 102 | 99 | 96 | 93 | 90 | 88 | 85 | 83 | 81 | 79 |
| 90800 | 85100 | 78700 | 71800 | 64300 | 60900 | 57400 | 53700 | 49800 | 45400 | 40600 | 35200 | 28800 | 66.5 | . . | . . | . . | . . | . . | . . | . . | 119 | 115 | 111 | 107 | 104 | 100 | 97 | 94 | 92 | 89 | 87 | 85 | 83 | 80 |
| 93000 | 87000 | 80600 | 73500 | 65800 | 62400 | 58800 | 55000 | 50900 | 46500 | 41600 | 36000 | 29400 | 67.0 | . . | . . | . . | . . | . . | . . | . . | 121 | 117 | 113 | 109 | 105 | 102 | 99 | 96 | 93 | 91 | 88 | 86 | 84 | 82 |
| 94600 | 88500 | 82000 | 74800 | 67000 | 63600 | 60000 | 56100 | 51900 | 47300 | 42400 | 36700 | 29900 | 67.5 | . . | . . | . . | . . | . . | . . | . . | . . | 119 | 115 | 111 | 107 | 104 | 100 | 98 | 95 | 92 | 90 | 88 | 85 | 83 |
| 96600 | 90400 | 83700 | 76400 | 68400 | 64800 | 61200 | 57200 | 52900 | 48300 | 43200 | 37400 | 30500 | 68.0 | . . | . . | . . | . . | . . | . . | . . | . . | 120 | 117 | 113 | 109 | 105 | 102 | 99 | 96 | 94 | 91 | 89 | 87 | 85 |
| 98600 | 92200 | 85300 | 77800 | 69600 | 66100 | 62400 | 58300 | 53900 | 49200 | 44000 | 38200 | 31200 | 68.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | 119 | 115 | 111 | 107 | 104 | 101 | 98 | 95 | 93 | 90 | 88 | 86 |
| 99800 | 93300 | 86300 | 78900 | 70600 | 66900 | 63100 | 59700 | 54700 | 49900 | 44600 | 38700 | 31600 | 69.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | 121 | 116 | 113 | 109 | 106 | 102 | 99 | 97 | 94 | 92 | 89 | 87 |
| 101900 | 95000 | 87200 | 80500 | 72200 | 68400 | 64500 | 60300 | 55800 | 50900 | 45400 | 39500 | 32200 | 69.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 118 | 114 | 111 | 107 | 104 | 101 | 98 | 95 | 93 | 91 | 88 |
| 103900 | 97200 | 88900 | 82100 | 73500 | 69800 | 65800 | 61500 | 56900 | 51900 | 46400 | 40100 | 32800 | 70.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 120 | 116 | 112 | 109 | 106 | 103 | 100 | 97 | 95 | 92 | 90 |
| 105700 | 98900 | 91600 | 83600 | 74800 | 71100 | 67000 | 62600 | 57900 | 52800 | 47300 | 40900 | 33500 | 70.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 118 | 114 | 111 | 107 | 104 | 101 | 98 | 96 | 93 | 91 |
| 107600 | 100600 | 93100 | 85000 | 75900 | 72200 | 68100 | 63600 | 58900 | 53800 | 48200 | 41700 | 34100 | 71.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 120 | 116 | 112 | 109 | 106 | 103 | 100 | 98 | 95 | 93 |
| 109300 | 102300 | 94600 | 86500 | 77300 | 73400 | 69100 | 64600 | 59900 | 54600 | 48800 | 42300 | 34600 | 71.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 118 | 114 | 111 | 107 | 104 | 102 | 99 | 96 | 94 |
| 111200 | 104200 | 96500 | 88100 | 78800 | 74800 | 70500 | 65900 | 61000 | 55700 | 49800 | 43200 | 35200 | 72.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 120 | 116 | 112 | 109 | 106 | 103 | 100 | 98 | 95 |
| 113000 | 105800 | 98000 | 89400 | 80000 | 75900 | 71600 | 66900 | 61900 | 56600 | 50600 | 43800 | 35800 | 72.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 118 | 114 | 111 | 108 | 105 | 102 | 99 | 97 |
| 115400 | 107900 | 99000 | 91200 | 81700 | 77500 | 73100 | 68400 | 63200 | 57700 | 51600 | 44700 | 36500 | 73.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 120 | 116 | 113 | 109 | 106 | 103 | 101 | 98 |
| 117200 | 109700 | 101600 | 92600 | 82900 | 78600 | 74200 | 69400 | 64200 | 58600 | 52400 | 45400 | 37100 | 73.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 118 | 114 | 111 | 108 | 105 | 102 | 100 |
| 119800 | 112200 | 103900 | 94800 | 84700 | 80400 | 75800 | 70900 | 65700 | 59800 | 53600 | 46400 | 37900 | 74.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 119 | 116 | 113 | 110 | 107 | 104 | 101 |
| 121500 | 113500 | 105200 | 96200 | 86000 | 81600 | 76900 | 71900 | 66500 | 60700 | 54300 | 47100 | 38400 | 74.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 121 | 118 | 114 | 111 | 108 | 105 | 103 |
| 123000 | 115000 | 106600 | 97500 | 87200 | 82700 | 78000 | 72900 | 67500 | 61600 | 55100 | 47700 | 39000 | 75.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 119 | 116 | 113 | 110 | 107 | 104 |
| 125200 | 117100 | 108500 | 99000 | 88500 | 83900 | 79300 | 74100 | 68600 | 62600 | 56000 | 48500 | 39600 | 75.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 121 | 118 | 114 | 111 | 108 | 106 |
| 127200 | 118800 | 110000 | 100400 | 89900 | 85200 | 80400 | 75200 | 69700 | 63600 | 56800 | 49200 | 40200 | 76.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 119 | 116 | 113 | 110 | 107 |
| 129200 | 120800 | 111900 | 102100 | 91300 | 86600 | 81800 | 76400 | 70800 | 64600 | 57800 | 50000 | 40800 | 76.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 121 | 118 | 115 | 112 | 109 |
| 131800 | 123100 | 114000 | 104100 | 93000 | 88300 | 83400 | 77800 | 72000 | 65800 | 58800 | 50900 | 41600 | 77.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 120 | 116 | 113 | 110 |
| 133800 | 125000 | 115700 | 105600 | 94400 | 89600 | 84600 | 79000 | 73100 | 66800 | 59700 | 51700 | 42200 | 77.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 118 | 115 | 112 |
| 136000 | 127100 | 117800 | 107500 | 96100 | 91100 | 86000 | 80400 | 74500 | 68100 | 60800 | 52600 | 42900 | 78.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 120 | 116 | 113 |
| 138000 | 128900 | 119500 | 109100 | 97700 | 92600 | 87400 | 81600 | 75600 | 69100 | 61800 | 53600 | 43600 | 78.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 118 | 115 |
| 140400 | 131100 | 121600 | 111000 | 99400 | 94300 | 89100 | 83100 | 77000 | 70300 | 62900 | 54400 | 44400 | 79.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 120 | 117 |
| 142800 | 133200 | 123400 | 112800 | 100800 | 95700 | 90200 | 84400 | 78100 | 71300 | 63800 | 55300 | 45100 | 79.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 118 |
| 144900 | 135300 | 125500 | 114700 | 102400 | 97100 | 91600 | 85700 | 79300 | 72400 | 64800 | 56100 | 45800 | 80.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | 120 |
| 146900 | 137200 | 127200 | 116200 | 103900 | 98600 | 93000 | 86900 | 80500 | 73500 | 65700 | 56800 | 46400 | 80.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| 149200 | 139500 | 129200 | 118100 | 105600 | 100000 | 94500 | 88400 | 81800 | 74700 | 66800 | 57800 | 47200 | 81.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| 151800 | 141800 | 131300 | 120000 | 107200 | 101600 | 95900 | 89800 | 83100 | 75800 | 67900 | 58800 | 48100 | 81.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| 154300 | 144400 | 133900 | 122100 | 109100 | 103400 | 97500 | 91300 | 84500 | 77200 | 68900 | 59700 | 48800 | 82.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| 156200 | 146200 | 135400 | 123700 | 110400 | 104800 | 98800 | 92600 | 85700 | 78300 | 70000 | 60600 | 49500 | 82.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| 159000 | 148800 | 137900 | 125800 | 112600 | 106700 | 100600 | 94100 | 87100 | 79600 | 71200 | 61600 | 50300 | 83.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| 161100 | 150400 | 139700 | 127300 | 113900 | 108100 | 102100 | 95300 | 88200 | 80700 | 72200 | 62400 | 50900 | 83.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| 163600 | 153100 | 141900 | 129400 | 115800 | 109600 | 103700 | 96900 | 89700 | 81900 | 73400 | 63400 | 51800 | 84.0 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| 166800 | 156000 | 144200 | 131800 | 117700 | 111800 | 105500 | 98500 | 91300 | 83300 | 74600 | 64500 | 52600 | 84.5 | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . | . . |

NOTE:—Tables figured for C. I. pipes: for concrete ducts, friction is 50% more.

## TABLE VIII

### AIR DUCTS EQUALIZED FOR CONSTANT FRICTION (B. F. STURTEVANT CO.)

| Dia. In Inches | CORRESPONDING RECTANGULAR DUCT | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 | 92 | 94 | 96 | 98 | 100 |
| 65.5 | 76 | 74 | 73 | 71 | 70 | 68 | 67 | 66 | 64 | 63 | 62 | 61 | 60 | 59 | 57 | 55 | 54 | 52 | 51 | .. | 48 | 47 | 46 | 45 | 44 | 43 | 42 | .. | .. | 40 | 39 | .. | .. | 37 |
| 66.0 | 77 | 76 | 74 | 72 | 71 | 69 | 68 | 67 | 65 | 64 | 63 | 62 | 61 | 60 | 58 | 56 | .. | 53 | .. | 50 | 49 | 48 | .. | .. | .. | .. | 43 | 42 | 41 | .. | .. | 39 | 38 | .. |
| 66.5 | 79 | 77 | 75 | 74 | 72 | 70 | 69 | 68 | 66 | 65 | 64 | 63 | 62 | 61 | 59 | 57 | 55 | 54 | 52 | 51 | 50 | .. | 47 | 46 | 45 | 44 | .. | .. | .. | 41 | 40 | .. | 39 | 38 |
| 67.0 | 80 | 78 | 76 | 75 | 73 | 72 | 70 | 69 | 67 | 66 | 65 | 64 | 63 | 62 | 60 | 58 | 56 | .. | 53 | 52 | .. | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | .. | 41 | 40 | .. | .. |
| 67.5 | 81 | 79 | 78 | 76 | 74 | 73 | 71 | 70 | 68 | 67 | 66 | 65 | 64 | 63 | .. | 59 | 57 | 55 | 54 | .. | 51 | 50 | 49 | .. | .. | .. | .. | 44 | 43 | 42 | .. | .. | 40 | 39 |
| 68.0 | 83 | 81 | 79 | 77 | 75 | 74 | 72 | 71 | 70 | 68 | 67 | 66 | 65 | 64 | 61 | 60 | 58 | 56 | 55 | 53 | 52 | .. | .. | 48 | 47 | 46 | 45 | .. | .. | .. | 42 | 41 | .. | .. |
| 68.5 | 84 | 82 | 80 | 78 | 76 | 75 | 73 | 72 | 71 | 69 | 68 | 67 | 66 | .. | 62 | .. | 59 | 57 | .. | 54 | .. | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | .. | .. | .. | 40 |
| 69.0 | 85 | 83 | 81 | 79 | 78 | 76 | 74 | 73 | 72 | 70 | 69 | 68 | .. | 65 | 63 | 61 | .. | 58 | 56 | 55 | 53 | 52 | 51 | .. | .. | .. | .. | .. | .. | 44 | 43 | 42 | .. | 41 |
| 69.5 | 86 | 84 | 82 | 81 | 79 | 77 | 76 | 74 | 73 | 71 | 70 | 69 | 67 | 66 | 64 | 62 | 60 | .. | 57 | .. | 54 | 53 | .. | 50 | 49 | 48 | 47 | 46 | 45 | .. | .. | 43 | 42 | .. |
| 70.0 | 88 | 86 | 84 | 82 | 80 | 78 | 77 | 75 | 74 | 72 | 71 | 70 | 68 | 67 | 65 | 63 | 61 | 59 | 58 | 56 | 55 | .. | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | .. | .. | 42 |
| 70.5 | 89 | 87 | 85 | 83 | 81 | 80 | 78 | 76 | 75 | 73 | 72 | 71 | 69 | 68 | 66 | 64 | 62 | 60 | .. | 57 | .. | 54 | 53 | 52 | .. | .. | .. | .. | .. | .. | 45 | 44 | 43 | .. |
| 71.0 | 90 | 88 | 86 | 84 | 82 | 81 | 79 | 78 | 76 | 74 | 73 | 72 | 70 | 69 | 67 | 65 | 63 | 61 | 59 | 58 | 56 | 55 | 54 | .. | 51 | 50 | 49 | 48 | 47 | 46 | .. | .. | 44 | 43 |
| 71.5 | 92 | 90 | 88 | 86 | 84 | 82 | 80 | 79 | 77 | 76 | 74 | 73 | 72 | 70 | 68 | 66 | 64 | 62 | 60 | 59 | 57 | 56 | .. | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | .. | .. |
| 72.0 | 93 | 91 | 89 | 87 | 85 | 83 | 82 | 80 | 78 | 77 | 75 | 74 | 73 | 71 | 69 | 67 | 65 | 63 | 61 | .. | 58 | .. | 55 | 54 | 53 | .. | .. | .. | .. | .. | .. | 46 | 45 | 44 |
| 72.5 | 94 | 92 | 90 | 88 | 86 | 84 | 83 | 81 | 79 | 78 | 76 | 75 | 74 | 72 | 70 | 68 | 66 | 64 | 62 | 60 | 59 | 57 | 56 | .. | .. | 52 | 51 | 50 | 49 | 48 | 47 | .. | .. | .. |
| 73.0 | 96 | 94 | 91 | 89 | 87 | 86 | 84 | 82 | 80 | 79 | 77 | 76 | 75 | 73 | 71 | 69 | .. | 65 | 63 | 61 | .. | 58 | .. | 55 | 54 | 53 | 52 | .. | .. | 49 | 48 | 47 | 46 | 45 |
| 73.5 | 97 | 95 | 93 | 91 | 89 | 87 | 85 | 83 | 82 | 80 | 78 | 77 | 76 | 74 | 72 | 70 | 67 | .. | 64 | 62 | 60 | 59 | 57 | 56 | 55 | .. | .. | 51 | 50 | .. | .. | .. | .. | 46 |
| 74.0 | 99 | 96 | 94 | 92 | 90 | .. | 86 | 85 | 83 | 81 | 80 | 78 | 77 | 75 | 73 | .. | 68 | 66 | .. | 63 | 61 | .. | 58 | 57 | .. | 54 | 53 | .. | 51 | 50 | 49 | 48 | 47 | .. |
| 74.5 | 100 | 98 | 96 | 93 | 91 | 89 | 87 | 86 | 84 | 82 | 81 | 79 | 78 | 76 | 74 | 71 | 69 | 67 | 65 | .. | 62 | 60 | 59 | .. | 56 | 55 | 54 | 52 | .. | .. | .. | 49 | 48 | 47 |
| 75.0 | 102 | 99 | 97 | 95 | 93 | 91 | 89 | 87 | 85 | 84 | 82 | 80 | 79 | 78 | 75 | 72 | 70 | 68 | 66 | 64 | 63 | 61 | 60 | 58 | 57 | 56 | .. | 53 | 52 | 51 | 50 | .. | .. | .. |
| 75.5 | 103 | 101 | 98 | 96 | 94 | 92 | 90 | 88 | 86 | 85 | 83 | 82 | 80 | 79 | 76 | 73 | 71 | 69 | 67 | 65 | .. | 62 | .. | 59 | 58 | .. | 55 | 54 | 53 | 52 | 51 | 50 | 49 | 48 |
| 76.0 | 105 | 102 | 100 | 97 | 95 | 93 | 91 | 89 | 88 | 86 | 84 | 83 | 81 | 80 | 77 | 74 | 72 | 70 | 68 | 66 | 64 | 63 | 61 | 60 | .. | 57 | 56 | 55 | .. | .. | .. | .. | 50 | 49 |
| 76.5 | 106 | 103 | 101 | 99 | 97 | 95 | 93 | 91 | 89 | 87 | 85 | 84 | 82 | 81 | 78 | 75 | 73 | 71 | 69 | 67 | 65 | .. | 62 | .. | 59 | 58 | .. | .. | 54 | 53 | 52 | 51 | .. | .. |
| 77.0 | 108 | 105 | 103 | 100 | 98 | 96 | 94 | 92 | 90 | 88 | 87 | 85 | 83 | 82 | 79 | 76 | 74 | 72 | 70 | 68 | 66 | 64 | 63 | 61 | 60 | .. | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 |
| 77.5 | 109 | 106 | 104 | 101 | 99 | 97 | 95 | 93 | 91 | 90 | 88 | 86 | 84 | 83 | 80 | 77 | 75 | 73 | 71 | 69 | 67 | 65 | .. | 62 | 61 | 59 | 58 | 57 | 56 | .. | .. | .. | .. | .. |
| 78.0 | 111 | 108 | 105 | 103 | 101 | 99 | 96 | 94 | 93 | 91 | 89 | 87 | 86 | 84 | 81 | 78 | 76 | 74 | 72 | 70 | 68 | 66 | 64 | 63 | .. | 60 | 59 | .. | .. | 55 | 54 | 53 | 52 | 51 |
| 78.5 | 112 | 109 | 107 | 104 | 102 | 100 | 98 | 96 | 94 | 92 | 90 | 88 | 87 | 85 | 82 | 80 | 77 | 75 | .. | .. | 69 | 67 | 65 | 64 | 62 | 61 | .. | 58 | 57 | 56 | 55 | 54 | 53 | 52 |
| 79.0 | 114 | 111 | 108 | 106 | 103 | 101 | 99 | 97 | 95 | 93 | 91 | 90 | 88 | 86 | 83 | 81 | 78 | 76 | 73 | 71 | .. | 68 | 66 | .. | 63 | .. | 60 | 59 | 58 | .. | .. | .. | .. | .. |
| 79.5 | 115 | 112 | 110 | 107 | 105 | 103 | 100 | 98 | 96 | 94 | 93 | 91 | 89 | 88 | 85 | 82 | 79 | 77 | 74 | 72 | 70 | .. | 67 | 65 | 64 | 62 | 61 | 60 | .. | 57 | 56 | 55 | 54 | 53 |
| 80.0 | 117 | 114 | 111 | 109 | 106 | 104 | 102 | 100 | 98 | 96 | 94 | 92 | 90 | 89 | 86 | 83 | 80 | 78 | 75 | 73 | 71 | 69 | 68 | 66 | .. | 63 | 62 | .. | 59 | 58 | 57 | 56 | 55 | 54 |
| 80.5 | 118 | 116 | 113 | 110 | 108 | 105 | 103 | 101 | 99 | 97 | 95 | 93 | 91 | 90 | 87 | 84 | 81 | 79 | 76 | 74 | 72 | 70 | .. | 67 | 65 | 64 | .. | 61 | 60 | .. | .. | .. | .. | .. |
| 81.0 | 120 | 117 | 114 | 112 | 109 | 107 | 105 | 102 | 100 | 98 | 96 | 94 | 93 | 91 | 88 | 85 | 82 | 80 | 77 | 75 | 73 | 71 | 69 | 68 | 66 | 65 | 63 | 62 | .. | 59 | 58 | 57 | 56 | 55 |
| 81.5 | .. | 119 | 116 | 113 | 111 | 108 | 106 | 104 | 102 | 100 | 98 | 96 | 94 | 92 | 89 | 86 | 83 | 81 | 78 | 76 | 74 | 72 | 70 | .. | 67 | .. | 64 | .. | 61 | 60 | 59 | 58 | 57 | 56 |
| 82.0 | .. | 120 | 117 | 115 | 112 | 110 | 107 | 105 | 103 | 101 | 99 | 97 | 95 | 93 | 90 | 87 | 84 | 82 | 79 | 77 | 75 | 73 | 71 | 69 | 68 | 66 | 65 | 63 | 62 | 61 | .. | .. | .. | .. |
| 82.5 | .. | .. | 119 | 116 | 114 | 111 | 109 | 106 | 104 | 102 | 100 | 98 | 96 | 95 | 91 | 88 | 85 | 83 | 80 | 78 | 76 | 74 | 72 | 70 | .. | 67 | .. | 64 | 63 | .. | 60 | 59 | 58 | 57 |
| 83.0 | .. | .. | 121 | 118 | 115 | 112 | 110 | 108 | 105 | 103 | 101 | 99 | 98 | 96 | 92 | 89 | 86 | 84 | 81 | 79 | 77 | 75 | 73 | 71 | 69 | 68 | 66 | 65 | .. | 62 | 61 | 60 | 59 | .. |
| 83.5 | .. | .. | .. | 119 | 116 | 114 | 111 | 109 | 107 | 105 | 103 | 101 | 99 | 97 | 94 | 90 | 87 | 85 | 82 | 80 | 78 | 76 | 74 | 72 | 70 | .. | 67 | .. | 64 | 63 | .. | .. | .. | 58 |
| 84.0 | .. | .. | .. | 121 | 118 | 115 | 113 | 110 | 108 | 106 | 104 | 102 | 100 | 98 | 95 | 92 | 88 | 86 | 83 | 81 | 79 | .. | 75 | 73 | 71 | 69 | 68 | 66 | 65 | 64 | .. | 61 | 60 | 59 |
| 84.5 | .. | .. | .. | .. | 120 | 117 | 114 | 112 | 110 | 107 | 105 | 103 | 101 | 99 | 96 | 93 | 90 | 87 | 84 | 82 | 80 | 77 | .. | 74 | 72 | 70 | .. | 67 | .. | .. | 63 | 62 | 61 | .. |

| Dia. In Inches | Corresponding Rect. Duct | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 84 | 86 | 88 | 90 | 92 | 94 | 96 | 98 | 100 |
| 85.0 | 71 | 69 | 68 | .. | 65 | 64 | .. | .. | 60 |
| 85.5 | 72 | 70 | 69 | 67 | 66 | .. | 63 | 62 | 61 |
| 86.0 | 73 | 71 | .. | 68 | 67 | 65 | 64 | 63 | 62 |
| 86.5 | .. | 72 | 70 | 69 | .. | 66 | 65 | .. | .. |
| 87.0 | 74 | 73 | 71 | .. | 68 | 67 | .. | 64 | 63 |
| 87.5 | 75 | .. | 72 | 70 | 69 | .. | 66 | 65 | 64 |
| 88.0 | 76 | 74 | 73 | 71 | 70 | 68 | 67 | 66 | .. |
| 88.5 | 77 | 75 | .. | 72 | 71 | 69 | 68 | .. | 65 |
| 89.0 | 78 | 76 | 74 | 73 | .. | 70 | .. | 67 | 66 |
| 89.5 | 79 | 77 | 75 | 74 | 72 | .. | 69 | 68 | .. |
| 90.0 | .. | 78 | 76 | .. | 73 | 71 | 70 | .. | 67 |
| 90.5 | 80 | .. | 77 | 75 | .. | 72 | 71 | 69 | 68 |
| 91.0 | 81 | 79 | 78 | 76 | 74 | 73 | .. | 70 | 69 |
| 91.5 | 82 | 80 | .. | 77 | 75 | .. | 72 | 71 | .. |
| 92.0 | 83 | 81 | 79 | 78 | 76 | 74 | 73 | .. | 70 |
| 92.5 | 84 | 82 | 80 | .. | 77 | 75 | 74 | 72 | 71 |
| 93.0 | 85 | 83 | 81 | 79 | 78 | 76 | .. | 73 | 72 |
| 93.5 | 86 | 84 | 82 | 80 | .. | 77 | 75 | 74 | .. |
| 94.0 | 87 | 85 | 83 | 81 | 79 | 78 | 76 | .. | 73 |
| 94.5 | 88 | 86 | 84 | 82 | 80 | .. | 77 | 75 | 74 |
| 95.0 | 89 | 87 | 85 | 83 | 81 | 79 | 78 | 76 | 75 |
| 95.5 | .. | .. | .. | .. | 82 | 80 | .. | 77 | .. |
| 96.0 | 90 | 88 | 86 | 84 | 83 | 81 | 79 | 78 | 76 |
| 96.5 | 91 | 89 | 87 | 85 | .. | 82 | 80 | .. | 77 |
| 97.0 | 92 | 90 | 88 | 86 | 84 | 83 | 81 | 79 | 78 |
| 97.5 | 93 | 91 | 89 | 87 | 85 | .. | 82 | 80 | .. |
| 98.0 | 94 | 92 | 90 | 88 | 86 | 84 | .. | 81 | 79 |
| 98.5 | 95 | 93 | 91 | 89 | 87 | .. | 83 | 82 | 80 |
| 99.0 | 96 | 94 | 92 | 90 | 88 | 86 | 84 | .. | 81 |
| 99.5 | 97 | 95 | 93 | 91 | 89 | 87 | 85 | 83 | 82 |
| 100.0 | 98 | 96 | 94 | 92 | 90 | 88 | 86 | 84 | .. |

NOTE:—Tables figured for C. I. pipes: for concrete ducts, friction is 50% more.

# TABLE IX

## AIR DUCTS EQUALIZED FOR CONSTANT FRICTION (B. F. STURTEVANT CO.)

| FRICTION PER 100 FOOT PIPE IN INCHES OF WATER | | | | | | | | | | | | | Dia. in Inches | CORRESPONDING RECTANGULAR DUCT | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .40 | .35 | .30 | .25 | .20 | .18 | .16 | .14 | .12 | .10 | .08 | .06 | .04 | | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 8 2 |
| Cubic Feet of Air per Minute | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 168200 | 157900 | 146000 | 133200 | 119100 | 113000 | 106800 | 99600 | 92400 | 84300 | 75400 | 65300 | 53300 | 85.0 | 118 | 116 | 113 | 111 | 109 | 107 | 105 | 103 | 101 | 97 | 94 | 91 | 88 | 85 | 83 | .. | 78 | 76 | .. | 73 |
| 171000 | 160000 | 148000 | 135000 | 120800 | 114500 | 108000 | 101000 | 93600 | 85500 | 76400 | 66200 | 54100 | 85.5 | 120 | 117 | 115 | 112 | 110 | 108 | 106 | 104 | 102 | 98 | 95 | 92 | 89 | 86 | 84 | 81 | 79 | 77 | 75 | .. |
| 173700 | 162500 | 150900 | 137400 | 123000 | 116500 | 109700 | 102800 | 95100 | 87000 | 77700 | 67400 | 54900 | 86.0 | .. | 119 | 116 | 114 | 112 | 109 | 107 | 105 | 103 | 100 | 96 | 93 | 90 | 87 | 85 | 82 | 80 | 78 | 76 | 74 |
| 176000 | 164900 | 152500 | 139300 | 124500 | 118000 | 111700 | 104300 | 96000 | 88200 | 78800 | 68200 | 55600 | 86.5 | .. | 120 | 118 | 115 | 113 | 111 | 109 | 106 | 104 | 101 | 97 | 94 | 91 | 88 | 86 | 83 | 81 | 79 | 77 | 75 |
| 178600 | 167000 | 154800 | 141000 | 126300 | 119500 | 113000 | 105300 | 97600 | 89200 | 79800 | 69100 | 56500 | 87.0 | .. | .. | 119 | 117 | 114 | 112 | 110 | 108 | 106 | 102 | 98 | 95 | 92 | 89 | 87 | 84 | 82 | 80 | 78 | 76 |
| 181200 | 169500 | 157000 | 143200 | 128000 | 121500 | 114500 | 107200 | 99400 | 90600 | 81000 | 70100 | 57300 | 87.5 | .. | .. | 121 | 118 | 116 | 113 | 111 | 109 | 107 | 103 | 100 | 96 | 93 | 90 | 88 | 85 | 83 | 81 | 79 | 77 |
| 184000 | 172200 | 159200 | 145700 | 130000 | 123700 | 116500 | 109000 | 100800 | 92100 | 82500 | 71300 | 58300 | 88.0 | .. | .. | .. | 120 | 117 | 115 | 113 | 110 | 108 | 104 | 101 | 98 | 94 | 92 | 89 | 86 | 84 | 82 | 80 | 78 |
| 186500 | 174400 | 161400 | 147300 | 132000 | 125000 | 118000 | 110200 | 102000 | 93500 | 83500 | 72300 | 59000 | 88.5 | .. | .. | .. | .. | 119 | 116 | 114 | 112 | 110 | 106 | 102 | 99 | 96 | 93 | 90 | 87 | 85 | 83 | 81 | 79 |
| 189000 | 177000 | 163800 | 149500 | 133800 | 126800 | 119500 | 112000 | 103400 | 94600 | 84600 | 73200 | 59800 | 89.0 | .. | .. | .. | .. | 120 | 118 | 115 | 113 | 111 | 107 | 103 | 100 | 97 | 94 | 91 | 89 | 86 | 84 | 82 | 80 |
| 192000 | 179800 | 166000 | 151600 | 135500 | 128500 | 121200 | 113200 | 105000 | 95800 | 86000 | 74400 | 60500 | 89.5 | .. | .. | .. | .. | .. | 119 | 117 | 115 | 112 | 108 | 105 | 101 | 98 | 95 | 92 | 90 | 87 | 85 | 83 | .. |
| 195000 | 182500 | 168000 | 154000 | 137200 | 130800 | 123000 | 115000 | 106800 | 97500 | 87200 | 75500 | 61500 | 90.0 | .. | .. | .. | .. | .. | 120 | 118 | 116 | 114 | 110 | 106 | 102 | 99 | 96 | 93 | 91 | 88 | 86 | .. | 81 |
| 197800 | 184500 | 171000 | 156000 | 139500 | 132000 | 124800 | 116800 | 108000 | 98600 | 88200 | 76400 | 62500 | 90.5 | .. | .. | .. | .. | .. | .. | 120 | 117 | 115 | 111 | 107 | 103 | 100 | 97 | 94 | .. | 89 | 87 | 84 | 82 |
| 200000 | 187000 | 173000 | 158000 | 141500 | 134200 | 126200 | 118000 | 109500 | 99800 | 89300 | 77400 | 63200 | 91.0 | .. | .. | .. | .. | .. | .. | .. | 119 | 116 | 112 | 108 | 105 | 101 | 98 | 95 | 92 | 90 | 88 | 85 | 83 |
| 202500 | 190000 | 175500 | 160000 | 143200 | 136000 | 128000 | 120000 | 110800 | 101200 | 90400 | 78500 | 64000 | 91.5 | .. | .. | .. | .. | .. | .. | .. | 120 | 118 | 113 | 110 | 106 | 102 | 99 | 96 | 93 | 91 | 89 | 86 | 84 |
| 205800 | 192500 | 178200 | 162700 | 145500 | 138000 | 130200 | 121800 | 112800 | 102900 | 92000 | 79700 | 65100 | 92.0 | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 115 | 111 | 107 | 104 | 100 | 97 | 94 | 92 | 90 | 87 | 85 |
| 208700 | 195200 | 180700 | 165000 | 147600 | 140000 | 132000 | 123500 | 114300 | 104300 | 93300 | 80800 | 66000 | 92.5 | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 116 | 112 | 108 | 105 | 102 | 98 | 96 | 93 | 91 | 88 | 86 |
| 211400 | 197700 | 183100 | 167100 | 149500 | 141800 | 133700 | 125100 | 115800 | 105700 | 94500 | 81900 | 66900 | 93.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 117 | 113 | 110 | 106 | 103 | 100 | 97 | 94 | 92 | 89 | 87 |
| 214200 | 200400 | 185600 | 169400 | 151500 | 143700 | 135500 | 126800 | 117300 | 107100 | 95800 | 83000 | 67800 | 93.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 115 | 111 | 107 | 104 | 101 | 98 | 95 | 93 | 90 | 88 |
| 217200 | 203200 | 188100 | 171700 | 153600 | 145700 | 137400 | 128500 | 119000 | 108600 | 97100 | 84100 | 68700 | 94.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 116 | 112 | 108 | 105 | 102 | 99 | 96 | 94 | 91 | 89 |
| 220000 | 205800 | 190500 | 173900 | 155600 | 147600 | 139200 | 130200 | 120500 | 110000 | 98400 | 85200 | 69500 | 94.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 117 | 113 | 110 | 106 | 103 | 100 | 97 | 95 | 92 | 90 |
| 223000 | 208600 | 193100 | 176300 | 157700 | 149600 | 141000 | 131900 | 122100 | 111500 | 99700 | 86400 | 70500 | 95.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 115 | 111 | 107 | 104 | 101 | 98 | 96 | 93 | 91 |
| 226000 | 211400 | 195700 | 178600 | 159800 | 151600 | 142900 | 133700 | 123800 | 113000 | 101100 | 87500 | 71500 | 95.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 116 | 112 | 109 | 105 | 102 | 99 | 97 | 94 | 92 |
| 228900 | 214200 | 198300 | 181000 | 161900 | 163600 | 144800 | 135500 | 125400 | 114500 | 102400 | 88700 | 72400 | 96.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 117 | 113 | 110 | 106 | 103 | 100 | 98 | 95 | 93 |
| 231800 | 216900 | 200800 | 183300 | 163900 | 155500 | 145600 | 137200 | 127000 | 115900 | 103700 | 89800 | 73300 | 96.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 114 | 111 | 108 | 104 | 101 | 99 | 96 | 94 |
| 236000 | 219800 | 203500 | 185800 | 166200 | 157600 | 148600 | 139000 | 128700 | 117500 | 105100 | 91000 | 74300 | 97.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 116 | 112 | 109 | 106 | 103 | 100 | 97 | 95 |
| 238000 | 222700 | 206200 | 188200 | 168300 | 159700 | 150600 | 140900 | 130400 | 119000 | 106500 | 92200 | 75300 | 97.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 117 | 113 | 110 | 107 | 104 | 101 | 98 | 96 |
| 240900 | 225400 | 208700 | 190500 | 170400 | 161600 | 152400 | 142600 | 132000 | 120500 | 107700 | 93300 | 76200 | 98.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 115 | 111 | 108 | 105 | 102 | 99 | 97 |
| 243900 | 228200 | 211200 | 192800 | 172500 | 163600 | 154300 | 144300 | 133600 | 122000 | 109100 | 94500 | 77100 | 98.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 116 | 112 | 109 | 106 | 103 | 100 | 98 |
| 247200 | 231200 | 214000 | 195400 | 174800 | 165800 | 156300 | 146200 | 135400 | 123600 | 110500 | 95800 | 78200 | 99.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 117 | 113 | 110 | 107 | 104 | 101 | 99 |
| 250500 | 234300 | 216900 | 198000 | 177100 | 163000 | 158400 | 148200 | 137200 | 125300 | 112000 | 97000 | 79200 | 99.5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 118 | 115 | 111 | 108 | 105 | 102 | 100 |
| 253500 | 237100 | 219500 | 200400 | 179200 | 170000 | 160300 | 150000 | 138800 | 126800 | 113400 | 98000 | 80200 | 100.0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 120 | 116 | 112 | 109 | 106 | 103 | 101 |

NOTE:—Tables figured for C. I. pipes: for concrete ducts, friction is 50% more.

designer can choose at first a suitable friction. A beginner may choose a low friction per hundred feet which may result in a duct of unwieldy dimensions and excessive first cost. On the other hand, if designed on the basis of a high friction loss the system may require excessive power to deliver the air.

Where the total pressure drop that can be allowed in the duct work is ascertainable, knowing the approximate length of the duct, the friction per hundred feet can be determined. Having decided that a loss per hundred feet equal to 0.3 in. water gauge can be allowed (this would be suitable for many ventilating systems with a length of about a hundred feet) the volume delivered is chosen from the column under the head 0.3 in. If the system has only one outlet then the full volume is delivered through a uniform pipe. For instance, to deliver 30,000 cu. ft. per minute follow down the column 0.3 until the nearest quantity to the desired volume is found. On the table this is 29,900. Project to the right from this quantity and under the column "Dia. in inches" will be found 45, which is the size pipe to convey the volume of air. It may happen that a round pipe cannot be used and a wide low duct is required. Projecting further to the right will be found various corresponding rectangular sizes; thus, as equivalent to 45 in. dia. would be found a 74 in. by 24 in. or a 41 in. by 41 in. Determine the total length and multiply by the friction loss in inches per hundred foot of length.

Elbows and turns should be converted into equivalent lengths of pipe and added to the straight runs to obtain the total equivalent length.

Where the system has several outlets the volume per outlet should be first determined. Having settled upon the friction the volume nearest corresponding to the volume delivered through the last outlet (that is, the one most distant) is located on the table under the proper friction loss. To the right of this volume will be found the proper duct size in either round or rectangular. This is the duct size leading to the last outlet.

The volume for the next outlet is added to the volume delivered through the last to obtain the volume delivered through the next section of pipe. Follow down the same friction column until the new volume is found. Opposite this will be found the size pipe which conveys the air to the last two outlets or branches as the case may be. From this point on the procedure is the same and eventually the total volume to be delivered by the system and the duct size to carry it are arrived at. This would be the size duct to attach to the fan outlet.

It should be noted that for most ventilating systems the duct size at the fan outlet should be at least equal to or somewhat larger than the fan outlet.

## VENTILATION OF ELECTRICAL MACHINERY

### Fans

#### Centrifugal Cased and Axial Flow or Propeller Type

Centrifugal cased fans consist of a wheel mounted upon a shaft and rotating in a housing. The air is taken in through one or two openings in the sizes of the housing. The openings are concentric with the fan shaft. The discharge from the housing is usually through one, but sometimes two openings in the housing and in a direction at right angles to the shaft. The centrifugal fans considered will be confined to the single stage type and for pressures up to 8 in. water gauge.

A centrifugal fan may be compared to a hole with revolving blades around it. By centrifugal force the air between the blades is displaced and discharged, thereby creating a partial vacuum at the hole. Atmospheric pressure produces a flow through the hole, which is the inlet of the fan, thus filling the void between blades. As the revolving air between the blades must be thrown off in order to induce a flow through the inlet it is evident that the shape, arrangement and location of the blades has an influence on the discharge of the air. It can readily be conceived that the blades can be placed in such a way as to restrict the flow of air, while another arrangement will permit an easy and unobstructed flow. The blade form and its position is the most important factor in fan performance.

If the air leaves the fan without any compression it is evident that it can only flow until the velocity is expended. To do useful work a fan must compress the air so that as friction in the duct system destroys the velocity the compression head will be converted into velocity head and maintain the flow. Certain types of fan blades produce very little compression in the air, while others produce a considerable proportion of that produced by the fan. To make useful the work done by the blades, the scroll shaped housing has been developed. Its function is to convert some of the velocity of the air into compression and to collect the air so that it can be delivered through a duct to the point desired. Hence the form of the housing is of importance in fan design and performance. Further, the housing proportions vary for various blade forms, which makes it imperative to use the particular housing developed for a certain wheel with only that wheel.

Centrifugal fans are made with blades numbering from 4 to 64. The blades may be straight and radial, or curved forward, that is with a concave face on the advancing side, the curved blade may be radial, tilted forward or backward; blades may be curved backward or with a convex surface on the advancing side. Some fan blades are long; that is, they extend from the wheel periphery to near the center of the wheel; while others may be narrow, having a depth of but a small percentage of the wheel diameter. Still other forms are long and curved backward with the blade lying along the periphery and not extending greatly toward the center.

The performance characteristic of each type is distinctive. The application requirements of the air systems are peculiar; consequently, it is necessary for proper results to apply the fan whose characteristics are suitable for a particular system. The ordinary fan characteristics may be broadly divided into three classes; the straight radial blade, narrow curved forward blade and the long curved backward blade. The pressure volume and efficiency characteristics of these three will be briefly outlined.

When the outlet of an operating fan is blocked tight a pressure is produced and maintained in the housing. This pressure is usually known as the static no delivery pressure, often designated as "S.N.D." pressure. The pressure for a given speed is dependent upon the type of wheel, number and arrangement of blades, number and size of inlets and the design of the casing. It might be supposed that an excessive pressure would continue to build up in a blocked tight fan, but the blocked tight pressure soon reaches a point where any additional pressure due to pulsation becomes greater than average pressure between pulsations and a "blow back" through the inlet results. Thus a blocked tight fan operates as a series of pulsations that alternately result in air drawn in through the inlet and then blown back out of the inlet. What happens when the outlet is opened to permit air flow will be described for the fans with blades of the type above mentioned.

All fans delivering through a fixed orifice have the following characteristics: the volume varies directly as the speed, the pressure as the square of the speed and the horse-power as the cube of the speed. In all centrifugal fans except the fully curved backward blade fan the power at constant speed is increased with decreased resistance and this also holds for a range of 75 per cent of opening of the fully backward curved blade fan. In all centrifugal fans the power is least at blocked tight conditions. The propeller type on the other hand takes the least power under wide open or free discharge conditions and the power increases as the resistance is interposed until it takes the maximum power under blocked conditions.

**Straight Blade or Radial Blade Type**

Starting with a no-delivery condition, as soon as the outlet is slightly opened to permit an air flow, the pressure almost immediately begins to drop and as the outlet is still further opened the pressure decreases at a still more rapid rate, until with an unobstructed outlet we get but little static pressure. We get then a pressure volume curve as shown in Fig. 33. At the same time the horse-power required to drive the fan has been undergoing a change. Although the fan has been doing no useful work when blocked it has required power to rotate the wheel. Now as soon as air begins to flow the weight of air handled becomes of some moment and the fan begins to require more power and as the outlet is wider and wider opened the power becomes greater. We get a power curve that after the outlet is 30 per cent open becomes a straight line sloping upward from left to right on the chart. See Fig. 33, which has the blocked conditions at the origin of the chart at the left.

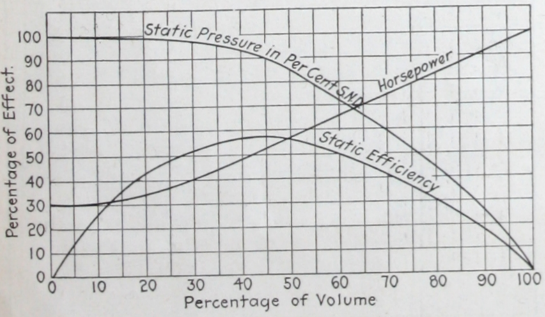


FIG. 33—STRAIGHT OR RADIAL BLADE FAN CHARACTERISTICS—CONSTANT SPEED.

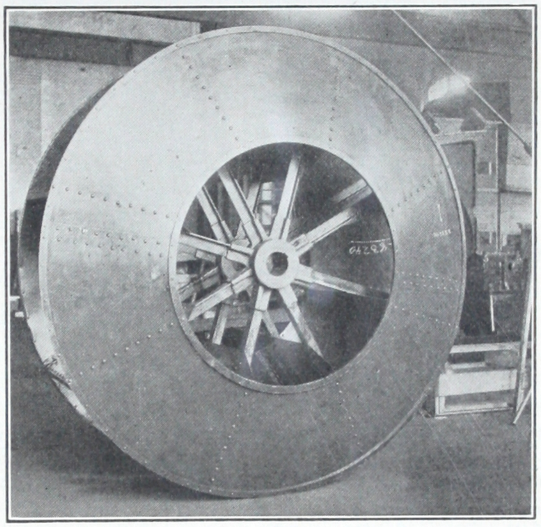


FIG. 34—STRAIGHT OR RADIAL BLADE FAN.

Doing no useful work blocked, the static efficiency is zero, but rises rapidly as the outlet is opened and reaches a maximum of about 55 per cent at a point of 40 per cent opening. From this point the static efficiency drops until it is practically zero at the wide open condition. It should be noted, however, that while the static efficiency is practically zero, the fan wide open is doing useful work and the total efficiency is approximately 25 per cent.

The *dropping* pressure characteristic, considering it from a blocked to open condition, or, better a *rising* pressure characteristic, considering it from an open to closed condition, is a desirable characteristic for certain fan duty such as for forced draft for furnaces, air cooled forced blast transformers or other duty where a variable pressure may be encountered. Whereas, in a forced draft for furnaces the resistance to the flow of air may be increased due to the thickening or clinkering of the fire, the straight blade fan will put up additional pressure to overcome the resistance with but a small percentage of decrease in volume of air delivered.

Due to the fact that the fan blades are quite long the inlet of the fan must be small and this requires operation at lightloads; that is, from 60 per cent to 70 per cent blocked for good efficiency. This re-

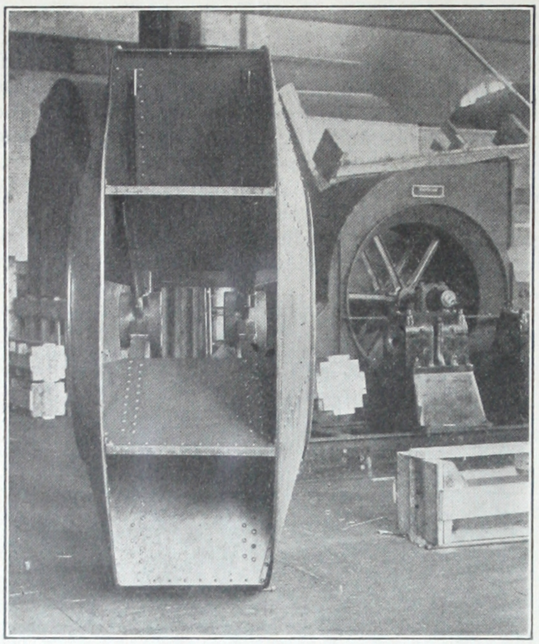


FIG. 35—STRAIGHT OR RADIAL BLADE FAN.

sults in a large fan for a small capacity and a slow speed fan not suitable for connection to high speed motors. Figs. 34 and 35 are typical of this type of fan.

### Forward Curved Multiblade Type

The forward curved type is usually found in the multiblade form having from 48 to 64 blades. The pressure characteristic in this fan is much different from the straight blade. As soon as the outlet is slightly opened the pressure drops sharply, further, opening finds the drop less pronounced until the pressure remains almost constant over a range of 40 per cent of total range of the outlet. This condition of almost constant pressure ceases at a point of about 60 per cent opening and from there on the pressure rapidly drops to the wide open point. See Fig. 36.

The horse-power curve of the curved forward blade fan rises rapidly and at a greater rate than the straight blade fan. This is due to the great volumetric capacity of the type of fan. As the blades are usually tilted forward the velocity of air leaving the blades under open conditions may be greater than the blade velocity. This can readily be shown by a velocity diagram. The efficiency of the multiblade curved forward fan is not much greater at its maximum point than the ordinary straight blade fan, but the maximum efficiency is maintained over a wide range of outlet opening and at a point from 40 to 60 per cent of wide open capacity. The volumetric capacity of the curved forward multiblade fan is very large. The narrow blades permit the largest inlet for a given wheel diameter. Due to the smaller space occupied for a given volume delivered and the high efficiency for operation at such a large percentage of wide open condition this type of fan has almost entirely supplanted the earlier straight blade type for ventilating purposes. It also operates at higher speed than the straight blade type, making more suitable for direct connected motor drive.

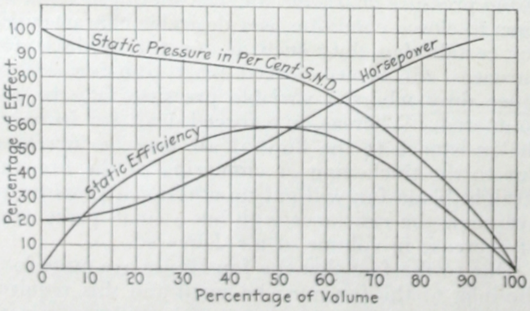


FIG. 36—FORWARD CURVED MULTIBLADE FAN CHARACTERISTICS—CONSTANT SPEED.

Where a nearly constant pressure will be encountered as in the usual ventilating system, the multiblade fan is suitable; but where a variable resistance is encountered unsatisfactory operation may result. Referring to Fig. 36 it will be noted that the maximum efficiency is at a point where the pressure starts to drop rapidly. This would be the point of application and it will be seen that for decreased volume—that is, moving to the left—there is very little rise in the pressure curve until the nearly closed point is reached. This means where a slight increase in pressure results the volume may be very much reduced before a sufficient higher pressure is developed to overcome the extra resistance. On the other hand, if the pressure is reduced the volume

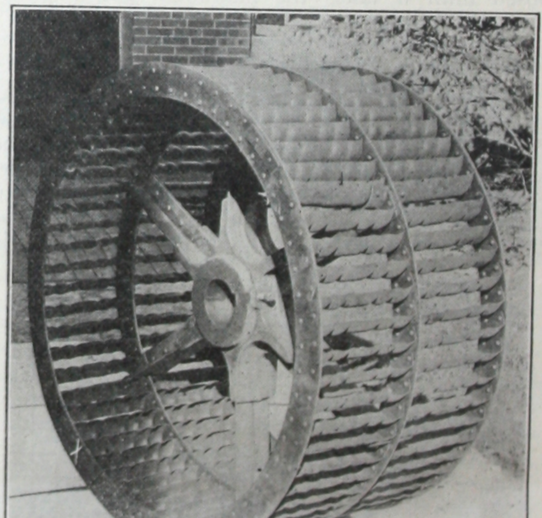


FIG. 37—FORWARD CURVED MULTIBLADE FAN.

becomes greatly increased and the horse-power required very much increased as will be seen from the horse-power curve.

Due to the large volumetric capacity and the flat pressure curve multiblade fans are not suitable for operation in parallel, as one fan may carry very much more than its share of the load. Because of the characteristics of this fan it is necessary, where the resistance of a system may vary or be difficult to predetermine, a considerable excess of driver capacity over that required for normal operating conditions must be allowed. Fig. 37 is a typical rotor for this style fan.

### Fully Curved Backward Type

The long curved backward type, of which Figs. 38, 39 and 40 are typical, has a more pronounced dropping pressure characteristic than the straight blade type. In some designs the pressure, when the fan is operating partially open, may even rise above the blocked tight pressure by some fifteen per cent. The pressure drop becomes pronounced beyond 40 per cent opening. The efficiency is maximum at 60 to 70 per cent of wide open. The efficiency curve is widened out at the maximum range, making it possible to choose a fan over a wider range of performance at high efficiency than is possible in other types. The static efficiency in addition may be over 70 per cent, which is very much above the other types.

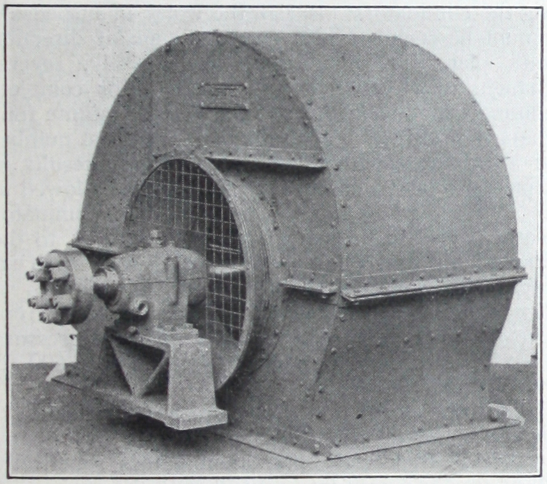


FIG. 38—FULLY CURVED BACKWARD BLADE FAN.

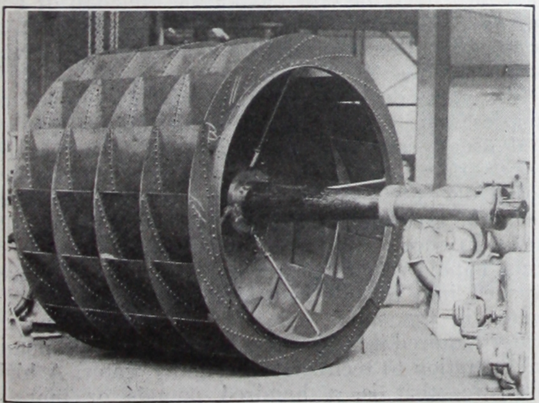


FIG. 39—FULLY CURVED BACKWARD BLADE FAN.

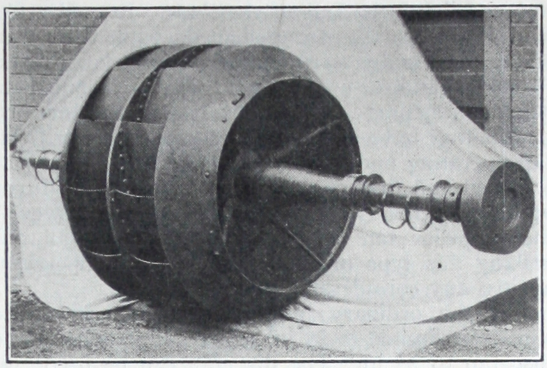


FIG. 40—FULLY CURVED BACKWARD BLADE FAN.

The horse-power curve of the backward curved blade type rises at a lesser angle and at about the working point it flattens out horizontally. In at least one design it even drops as the wide open condition is reached. This makes it possible to apply a motor whose rating is no more than the power required by the fan when it is applied beyond the maximum horse-power point. The pressure characteristic makes this type of fan desirable for forced draft and other service where variable resistance but nearly constant volume is desired. The fully backward curved blade fan operates quietly and efficiently at speeds double those of the multiblade type making them suitable for direct connection to alternating current motors for light pressures and to slow speed turbines at pressures required for forced draft. Fig. 41 shows pressure, volume, horse-power and efficiency curves of a typical backward curved fan.

### Propeller and Disc Type

Propeller and disc fans are axially flow fans; that is, the air flows into and from the wheel in a direc-

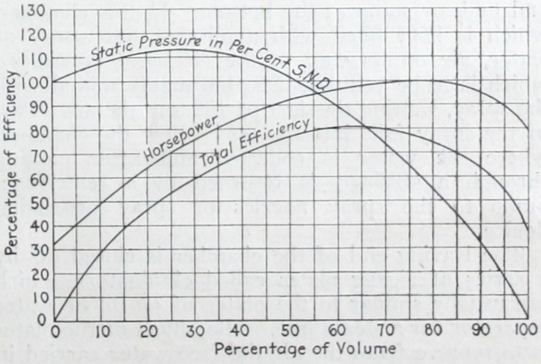


FIG. 41—FULLY CURVED BACKWARD BLADE FAN CHARACTERISTICS—CONSTANT SPEED.

tion parallel to the axis of the shaft. Propeller fan blades are usually scoop-shaped, while disc fan blades are usually warped into a section of a helix. Propeller and disc fans are usually installed to handle air against little or no resistance and for such service they have as good efficiency as a centrifugal fan operating under the same conditions, the space occupied and first cost are very much in the favor of the propeller type. Against resistance, however, the propeller fan capacity and efficiency fall off, making this type unsuitable for efficient operation against any considerable pressure.

For the ordinary propeller fan the resistance should be limited to ¼ in. water gauge and for the disc fan to ½ in. The disc fan can be used efficiently against a higher pressure than that customary for propeller fans, because they usually have overlapping blades and a large hub which tends to stop a reverse flow through the center of the wheel, which is moving at a much lower speed than the periphery.

For exhaust ventilation where air is discharged out of doors, the propeller type will handle a surprisingly large volume for a small operating cost and a low first cost. For the removal of fume or vapor laden air, for removing excessively heated air under a roof or in a monitor, ventilating low head room basements, etc., the propeller type is customarily used.

## Air Washers

In this country commercial air washers, such as used for washing and cooling the air supply for ventilating electrical apparatus, are almost entirely of the spray type. Rotating metal or fixed cloth screens, coke washers and other wet filters are not commonly used in this country, but are quite generally used in Europe. As American practice is almost confined to the spray washers, this report will be confined to the details of their design. Most spray washers are designed along similar lines with only minor variations in construction details and nozzle design, consequently the following will cover the usual spray washer.

### Open System with Recirculated Water

First there will be considered the spray chamber, which is formed by a top casing, two side casings and tank or sump at the bottom. In this chamber, which is kept filled with a mist or fine spray of water, air on its way to the electrical apparatus, which is to be ventilated, is thoroughly mixed with the spray, wetting the dust particles in the air. Part of the spray falls into the tank below the chamber, where the water is collected and after passing through a strainer, is returned by a centrifugal pump to the spray nozzles or spray producing device.

The leaving end of the chamber is closed off by a series of zigzag plates called eliminators, which are usually similar to the plates of an oil or water separator for a steam line. The object of the plates is to remove from the air the free water carried in suspension. Due to the fineness of the spray and the velocity through the chamber a large amount of water is held in suspension. By changing the direction of flow of the air a number of times the water can be deposited upon the plates, which are usually provided with gutters to conduct the water to the sump below. It is evident that the angle of incidence of the plate to the air flow will determine the degree of separation. If the plates were at right angles to the air flow the elimination woul dbe 100 per cent, but such a plate would close the end of the chamber so that no air could flow. Consequently, the plates must be placed at some angle less than 90 degrees.

From a study of air flow it is known that the greater the degree of angle through which a stream of air is turned abruptly the greater the proportion of the velocity pressure lost by the change in direction. From experimentation it has been found that an angle of 45 degrees was about the limit that would not result in an excessive pressure drop passing the eliminators. But all the water in suspension cannot be removed in a single change of direction with plates at this angle; consequently, several changes in direction are produced. For complete elimination at velocities of 600 feet per minute four changes in direction are provided. But that number of air changes with the rubbing friction results in a pressure loss usually more than can be allowed in a ventilating system. Consequently, eliminator plates placed to present an angle of 30 deg. to the flow of air are commonly used and with such an angle it is quite usual to provide six changes in direction. Such plates are usually spaced from 1⅛ in. to 1½ in. apart. The drop in pressure varies from ⅜ in. to ½ in. water gauge at 600 ft. velocity per minute.

The function of the spray is to wet the dust particles; consequently, dividing the air into many streams by the closely spaced eliminators, practically all of the air comes into contact with the surface of the plates which are kept wet by the constantly impinging water particles. The wet dust particles readily adhere to the plate and are washed into the sump by the water that collects or by streams of water flowed over the plates. Thus, while the eliminators are necessary to remove the water in suspension they have the other important function of acting as a washing surface. The greater the area of wet surface that is provided the more complete will be the washing.

The spray device usually consists of a number of nozzles spaced over the area of the spray chamber and usually near the entering end. Most nozzles are of some form of centrifugal nozzle with various spiral devices to produce a mist. The nozzle presents the greatest problem of air washer design. It must produce a mist in the finest possible form, it must handle very dirty water, for much of the dust washed into the air is held in suspension in the water in the sump. Because of the volume of water required it is generally necessary for economical operation to recirculate the spray water. A high pressure—that is, a hundred pounds or more—through a very small orifice would produce the most desirable form of spray; but the water used in an air washer will soon clog a small orifice. A high pressure discharging through a large orifice would result in a large volume of water handled and a consequent excessive power consumption. It is therefore necessary to design the nozzle with a large orifice to pass the material carried in suspension and at the same time produce as fine spray as possible with a low pressure.

The centrifugal and spiral nozzle quite satisfactorily accomplishes this. Such nozzles are provided with orifices from ⅛ to ¼ inch in diameter, and deliver from 1 to 2 gallons per minute with pressures from 20 to 30 pounds.

The total length of the ordinary washer is from 6 to 8 feet. The nozzles are usually placed about four feet from the eliminators. In many designs an auxiliary spraying device is placed over the eleminators to keep them flooded with water to wash into the tank the dust impinging upon them. The casing of the spray chamber is usually provided with an access door and the interior is lighted by marine type fixture. Strainers are usually provided in the sump and in the suction or discharge line of the pump. Recirculating pumps are usually of the enclosed impeller split casing double suction type.

Due to the finely divided state of the spray water, evaporation takes place rapidly. The air will leave a washer in a saturated state or nearly so. As evaporation requires heat a reduction in temperature takes place. As no heat is added to the water (except when, for reasons given later, outside air at temperatures near the freezing point of water is taken through the washer), the heat required for evaporation comes from the air. The heat of the air then is made up of sensible heat, the latent heat of vaporization of the water vapor present in the air and the sensible heat of the water vapor. As no outside heat has been added it is evident that the total heat of the air entering and leaving must remain constant and the reduction of sensible heat must be equal to the increased latent heat of the increased water vapor that the leaving air carries.

The wet bulb temperature of the air is the temperature of vaporization and is a measure of the total heat in the air and as the total does not change, the wet bulb temperature of the air passing through the washer does not change. Further the spray water temperature when recirculated assumes the wet bulb temperature of air. The air cannot be cooled below the wet bulb temperature, which is the water temperature, for at that temperature a further exchange of heat is not possible. The evaporation necessary to bring the air to the wet bulb temperature results in complete saturation of the air, making further evaporation impossible. Hence the maximum cooling possible with recirculated spray water is to the wet bulb temperature of the entering air.

The reduction in temperature of air by evaporation of the spray water provides a maximum air temperature for cooling and ventilating a generator seldom exceeding 75 deg. fahr. A high temperature out of doors is rarely accompanied by a high humidity; consequently, when a reduction in the air temperature is most needed it is almost always attainable. In certain parts of the Southwest where temperatures of more than a hundred are not uncommon they are usually accompanied by relative humidities of 20 per cent and lower, which makes possible a reduction of 20 to 30 deg. fahr. by the evaporation of the spray water in a washer using recirculated water.

In localities where outside temperatures below 40 deg. fahr. are encountered it is necessary to heat either the air or the spray water when such air is taken through the washer. The heating of the air can be accomplished by the usual blast heating coils, while for heating the water an ejector heater is placed in the pump suction or the tank. The air if heated by the blast coils, should be heated to a temperature not less than 40 deg. fahr. and preferably to 45 deg. It is possible to form mushy ice on the eliminators of an air washer when 40 deg. fahr. air is entering the washer. If the outside air is very dry and of low temperature, its wet bulb temperature when heated to 40 deg. may be below 32 deg. and the temperature reduction which takes place due to evaporation may result in a leaving temperature under 32 deg. with the result that ice may form on the eliminators. Such a condition may tear down the eliminators, but of more serious consequence is the stoppage of the flow of air necessary to ventilate the generator. A thermometer for indicating the temperature of the air leaving the washer should be placed in the air duct just beyond the eliminators, rather than before the air washer. A temperature of 40 deg. at the leaving point is a safe one.

The air, when it is heated by the water which is heated by steam ejectors or other means, leaves the washer completely saturated. In this condition care should be taken that there is no leakage of cold air into ducts beyond the washer, nor should the ducts be so constructed or located to present very cold surfaces which might cause a drop in temperature of this saturated air, which would result in precipitation. The vapor condensed may be carried along with the air on the windings of the machine. With the air heated instead of the water heated there is a certainty in many types of washers of air leaving the washer somewhat less than saturated so that a reduction of two or three degrees would be necessary before condensation takes place.

The air velocity through the spray chamber is usually confined to 500-700 feet per minute and at such velocities the resistance to the flow of air or the pressure drop will be from ¼ to ½ inch water gauge. The amount of water sprayed will vary four to eight gallons per thousand cu. ft. washed per minute.

An efficient washer will remove more than 95 per cent of ordinary dirt carried in suspension in the air. Where, however, the amount of soot or carbon particles is a large percentage of the dust particles in the air, the washing efficiency may be much less. The air washer does not readily remove sooty particles. Because of the oily surface of such particles they do not wet and do not so readily adhere to the eliminator plates.

The most common construction for air washers is of galvanized iron and copper. Concrete construction for the sump and spray chamber casing is often used. Not enough attention has been given to possibilities of heavy plate steel that is ¼ to ⅜ in. thick for casing and tank. It might be expected that heavy boiler plate construction would more nearly meet the life of the turbine and generator than either light weight copper or galvanized iron.

### Open System with Continuous Water Supply

The washer construction for a continuous supply of water does not differ from the washer when recirculating the spray washer. The clearing efficiency does not change and the exchange of heat does not follow that which takes place when the spray water is recirculated. If the water supplied is above or below the wet bulb temperature of the air entering the washer, heat is added or subtracted and the change in temperature is no longer an adiabatic one as is the case when the spray water is recirculated.

The air temperature leaving the washer is dependent upon the difference in the heat of the air and the temperature of the water, the relative weights of air and water, the fineness of the spray and the length of time of contact. In a single spray washer using a pound of water to a pound of air, the difference in temperature between leaving air and leaving water will be approximately 25 per cent of the initial difference between air and water when air at ordinary outside temperatures is passed through the washer.

By spraying water much warmer than the entering air temperature the air can be heated. The heating of water in a washer is often resorted to when air temperatures near or below 32 deg. fahr. is washed.

As the volume of water required for a large washer will be several hundred gallons per minute, a continuous supply of water is not often used.

### Closed System of Ventilation

Due to the limitations of the air washer in removing dust, and the fire hazard with large volumes of air passing through the generator there has been developed the closed system in which the air is recirculated and not the water. The functioning of the washer under these conditions is the same as the washer in an open system using a continuous supply of water.

As the duct work required to connect the washer to the intake connection and outlet of the generator is often difficult to arrange satisfactorily many closed systems are arranged with the washer located inside of the generator foundation. This arrangement has the added advantage of using what might otherwise be waste space and at the same time leaves for the other apparatus the space outside of the foundation.

The construction of an air washer for location inside the foundation is usually special and has to be designed to fit the particular foundation. The chamber is usually divided into three parts; the middle one acting as a down take for the hot air from the generator; the two outside ones are usually the uptakes returning the air to the end bells of the machine. The spray nozzles may be located at the top of the downtake chamber with its water sprayed vertically downward with the air and with two sets of eliminators placed vertically at the bottom of the partition sheets which divide the chambers. A second arrangement is to place the spray nozzles near the bottom of the downtake and to spray the water vertically upward against the downward flowing air. The best contact between air and water is secured by this arrangement.

It is sometimes necessary, because of space conditions, to place the eliminators in a horizontal position in the uptake chambers. When this is done it is quite desirable, but not necessary, to divide the spray nozzles into two groups and to place them in the uptake chambers below the eliminators. When this is done the spray can be directed downward against the upward flowing air and intimate contact secured. This arrangement eliminates the danger of water being sprayed into the bottom outlet of the generator which might happen with the water sprayed upward in the central or downtake chamber. As a precaution, however, a set of eliminators should be installed at the top of the downtake chamber when the spray is directed upward in the central chamber.

The water used in the closed system is often the makeup water or the condensate from the turbines, or a combination of both.

### *Closed System at Light Loads*

At light loads the makeup water will be insufficient for cooling the air and under such conditions the system can be operated as a combined open and closed system. The available makeup water is supplied to the washer and mixes with water that is recirculated, the surplus amounting to the makeup water overflowing. To keep the water and air temperatures down to a safe operating temperature it is necessary to open the dampers of the system partially and admit a percentage of fresh air and to discharge part of the heated air.

## Air Washer Eliminators

Eliminators are usually the part of an air washer that has to be replaced first. This is due to the fact that they are usually of lighter gauge metal than other parts, customary because of the large amount of surface needed and the excessive weight that would result if made of the same gauge as the tank and casing. In addition they are subject to more erosion and corrosion than other parts. Due to the flow of dust and grit laden water over the plates the wear is quite pronounced, especially where the air contains abrasive dust. The mixture of air and water forms an acid solution on the plates if there is an acid gas present in the air. In the neighborhood of most power stations there is a slight amount of sulphur dioxide present in the air. This forms a weak acid solution with the spray water and in the presence of such large volumes of air passing through the washer steel or iron is attacked.

Eliminators to withstand this action are made of copper, aluminum and lead containing a small percentage of antimony and lead coated steel. Copper is one of the most satisfactory non-corrosive metals and will usually have sufficient additional length of life to warrant its use. It is easy to work and has enough strength to support itself constructed in eliminators of some length. If all parts used are copper so that electrolytic action is not set up in the presence of weak acids the life of copper washers should be nearly twenty years. On the other hand, where dissimiliar metals are used, especially if galvanized iron is the other metal, quite rapid corrosion may be expected in the presence of weak acids and to the oxidization due to large air volumes. In such cases all galvanized iron construction will doubtless prove better.

Aluminum has been used to some extent. It appears to withstand the action of some weak acids but is quickly converted into a salt where alkalines are present and its use in the Rocky Mountains where there is a pronounced alkalinity of the water is quite certain to result in rapid destruction. The weak solution of carbonic acid formed by the spray water and carbon dioxide of the air has been sufficient to convert rapidly aluminum into aluminum carbonate. It is likely that in the presence of the carbon dioxide and water an electrolytic action takes place between the aluminum and the iron impurities that the aluminum contains converting the metal into aluminum and iron carbonates.

Lead is a satisfactory metal to withstand conditions such as are encountered in the air washers where large volumes of air in the presence of water and weak acids produce severe oxidizing conditions. Lead, however, is too soft and ductile for use as rather thin eliminator sheets and it is usually hardened by the addition of a few percent of antimony. But even this alloy when rolled into thin sheets does not have much strength or stiffness making it advisable to form the elminators in short sections, otherwise, they may sag out of line reducing the air passage in one place and increasing it in others with the result that elimination may not be complete. Care must be used in handling the eliminators during installation.

Lead coated steel offers the advantages of solid lead as regards resistance to corrosion and at the same time gives the stiffness and strength of steel, which makes it suitable for eliminator use. Early lead coating gave a surface which contained minute holes through which acids and fumes were able to attack the steel sheet beneath. The process has been so improved that the manufacturers of lead coated sheets are offering sheets free from this defect. Lead coated steel being lighter than the solid lead sheet it is more easily handled when made into eliminators and being stiffer and less ductile the liability to damage in shipment and erection is much reduced.

## Dry Filters (Fabric)

Dry filters are to a large extent used in European stations. The filters usually take the form of frames covered with a fabric which has considerable nap. The frames may be nested in various ways according to the idea of the designer. Some are mechanically rotated and others mechanically agitated. Screens in American practice are usually confined to a plain screen, zig zag screens and bag filters. See Figs. 42 and 43. Where a plain screen is placed over the entrance to or in an air duct it is almost sure to be of insufficient area, for rarely will a duct be made of a cross section that would result in the low velocity advisable for cloth filters.

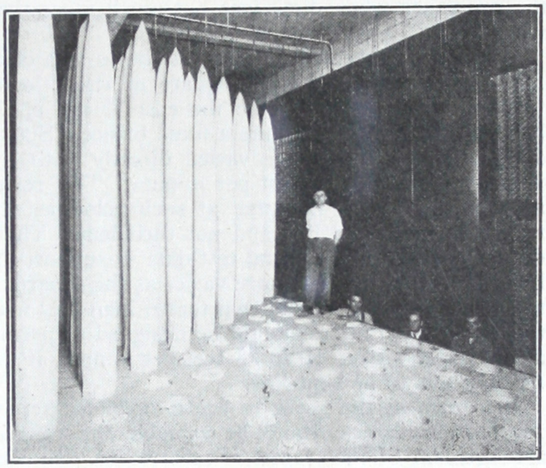


FIG. 42—DRY FILTERS—BAG TYPE.

The cloth should be of a flannel type, as the cleansing is accomplished by the particles of dust adhering to the fibres. An open weave with a large percentage of the air space between fibres is necessary. Such fibres as silk are not suitable for the

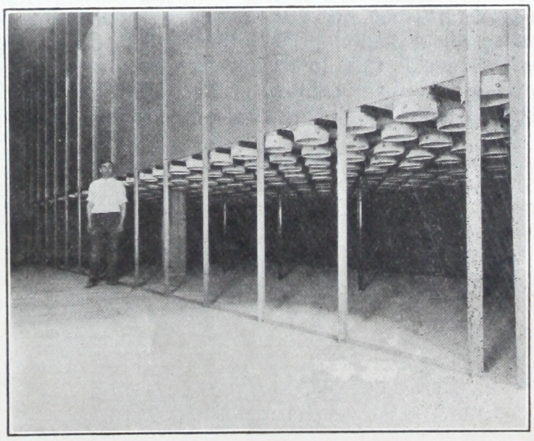


FIG. 43—DRY FILTERS—BAG TYPE.

interstices soon clog with dust particles and the resistance to the flow of air increases greatly. At the same time the high velocity through the partially clogged interstices tears loose some dust particles from the fibres, making the dust removal inefficient.

As reported in the *Journal A. S. H. & V. E.*, May, 1921, A. E. Stacey found the resistance to the flow of air interposed by a silk fabric, the meshes of which were clogged with carbon particles, seven times as great as when clean. The flannel type of fabric with a long nap retains the dust but still leaves a large area for air to pass through so that the resistance when dirty was not much more than when clean.

It might be expected that the resistance of a cloth filter is proportional to the square of the velocity through it. This would be the case if the opens between the fibres constitute a fixed orifice. Stacey found that the resistance varied directly with the velocity from 0 to 50 feet per minute. This result may be due to the fact that at such velocities the flow was in stream line and not turbulent. There do not appear to be at hand test data to support the hypothesis that the resistance varies as the square of the velocity, but as it is known that it increases with the velocity the filters should be designed to permit a low velocity from 50 to 75 feet per minute, if the resistance is to be kept low.

Inasmuch as the space to accommodate a screen for such velocities would be valuable the zig zag arrangement of the frames is resorted to. By this arrangement a large amount of surface can be placed in comparatively small cross sectional area. The frames are usually placed in guides and arranged to be readily removed for cleaning and replacement.

Bag filters are usually made of cloth sewed into a cylindrical form from 10 in. to 14 in. in diam. and for 6 ft. to 10 ft. long. One end is closed and usually finished off with a loop or hook to be attached to a frame. The other end is finished off with a metal ring to fit a collar on a plate which divides the bag chamber. The bags are usually spaced from 14 to 18 inches on centers. The bags may be inverted; that is, the open end at the bottom with the closed end at the top. Dust-laden air enters the bags from below and passes through meshes of the cloth, leaving behind the dust adhering to the cloth. With such an arrangement a large part of the dust can be shaken loose when the equipment is not in use, making the removal for cleaning less frequent. With the opening into the bag at the top the bags must be removed for cleaning.

### Viscous Surface Filters

There has been introduced in this country the Viscous surface filter which has been used quite widely in Europe. This filter consists of a wire mesh or expanded metal box filled in irregular order with ¼ in. to ½ in.-length thin brass or copper tubes from ¼ in. to ½ in. diam. The frame or filter cell is immersed in a bath of viscous oil and allowed to drain. It is then placed in a frame in the air intake to a ventilating system. The air passing through the tortuous passages around the tubes deposits its dust on the viscous surface of the tubes. To remove the dust the cell is immersed in a bath of hot water and soda which removes the viscous coating and dirt. The cells are then drained and dried and recharged again by dipping in the viscous oil. For large volumes of air the cells are made in units of size readily handled.

The vendor states the resistance is 3/16 in. water gauge. It is certain that this must vary with the state of cleanliness for when considerable dirt has been deposited on the tubes the area through which the air flow is reduced; in addition, the dust surface offers a higher resistance than the smooth surface of the tubes. Consequently, it is to be expected that the resistance will increase with an accumulation of dust. With the covering of the viscous surface with dust the cleansing efficiency must also vary. Dust does not adhere to dust as readily as it does to an oily surface.

It is usual to have a few extra filter cells for a large installation so that the cells can be cleaned one at a time. By replacing a dirty cell with a clean one continued operation is possible.